FINAL REPORT

RAPID ENERGY MODELING WORKFLOW DEMONSTRATION

ESTCP Project EW-201259

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John Sullivan
Jennifer Rupnow
Vincent Corsello
Autodesk, Inc.

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Jennifer Rupnow
John Sullivan

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111 McInnis Parkway
San Rafael, CA 94903

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14. ABSTRACT
The DoD has a critical need to evaluate energy consumption of existing facilities. To address this need Rapid Energy Modeling (REM) methodology was deployed. The workflow captures and information on operations and geometry of a building, generates a 3D building model and then simulates energy use patterns and reports on energy conservation measures. REM was applied to a sample of 23 DoD buildings. The simulated and actual building energy data was analyzed by energy type (electricity and natural gas) and energy use intensity (EUI).

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Acronyms and Definitions

3D	Three-dimensional
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BIM	Building Information Modeling
BPA	Building Performance Analysis
BTU	British Thermal Unit
CBECS	Commercial Building Energy Consumption Survey
CoV	Coefficient of Variation
CVRMSE	Coefficient of Variation of the Root Mean Square Error
DoD	Department of Defense
DOE-2.2	Department of Energy-2.2-the simulation engine contained within Autodesk Green Building Studio
ERDC-CERL	Engineer Research and Development Center, Construction Engineering Research Laboratory of the US Army Corps of Engineers
ECM	Energy Conservation Measures
EPD	Equipment Power Density
EUI	Energy Use Intensity
FM	Facilities Management
ft^2	Square foot or square feet
GBS	Green Building Studio, Autodesk service for energy analysis
GSA	General Services Administration
GSF	Gross Square Foot
kBtu	Thousand British Thermal Units
kWh	Kilowatt hours
LPD	Lighting Power Density
MAPE	Mean Absolute Percentage Error
MBE	Mean Bias Error
MMBtu	Million British Thermal Units
MEP	Design disciplines of Mechanical, Electrical and Plumbing engineering.
MFE	Mean Forecasting Error
O&M	Operations and Maintenance
PES	Potential Energy Savings
POC	Point of Contact
REM	Rapid Energy Modeling
STDEV	Standard Deviation
USACE	The United States Army Corps of Engineers
VA	The United States Department of Veterans Affairs

EXECUTIVE SUMMARY

The Department of Defense (DoD) energy success is measured against mandated goals for energy reduction and sustainable facility management. In order to make consistent and well-informed decisions across its entire portfolio of buildings, DoD has a critical need for a consistent, scalable approach to evaluating energy consumption of existing facilities, to compare tradeoffs between energy conservation measures, and to identify facilities that are in greatest need of improvement.

In the last several years, it has become increasingly evident that existing methods of simulating and estimating energy use in buildings require highly trained engineers to spend significant time constructing energy analysis simulations. Shortcomings of past approaches included labor-intensive data inputs, the need for subject matter experts to operate the modeling systems, and the inability to model the DoD building inventory in a timely or cost effective way. Autodesk began looking at ways to combine various data collection methods, best practices and software tools to address this problem, and the idea of Rapid Energy Modeling (REM) was conceived.

Overall, the goal of the demonstration was to evaluate REM workflows and performance by comparing simulated to actual building energy consumption and investigate the scalability of REM workflows for the DoD. This project demonstrated that the REM workflow quickly captures and utilizes information on operations, geometry, orientation, weather, and materials, generates 3D Building Information Models (BIM) guided by satellite views of building footprints and simulates energy use patterns. In addition, the project demonstrated the application of simulated Energy Conservation Measures (ECMs) on a subset population of buildings to understand effective ways to reduce their energy consumption. The REM technology including the ECM capabilities uses whole-building energy simulation algorithms driven by the DOE-2.2 engine for energy analysis (Figure 1).

REM was applied to a sample of 23 DoD buildings across 8 locations and representing 7 building types. The simulated and actual building energy data was analyzed by energy type (electricity and natural gas) and energy use intensity (EUI) and further segregated by building type. The results show that the models for offices and specialty use buildings performed better than models for barracks, where variable occupancy did not match model assumptions.

Quantitatively, a primary performance objective was to have REM electric and natural gas estimates come within $\leq$ 10% of actual utility information (90% average accuracy). Aggregate results indicate average accuracy of 81.88% for predicting electric consumption with a mean absolute percentage error of 18.12% (Table 7), considered to be a good forecast according to published criteria (Lewis 1982). Natural gas and combined EUI predictions were on average 58.20% accurate and 77.56% accurate respectively, considered reasonably accurate (Table 2). The demonstration produced margins that while outside the target range, were still within the range of useful forecasting values (Table 2), with strong correlations in energy use curves for many buildings.

Qualitatively, the training completed to date indicates that the project meets the performance objectives showing that DoD participants can learn the workflow and begin creating and analyzing using REM in less than one day. Participants also indicate a high level of satisfaction with the REM workflow. Preliminary results indicate that energy models can be completed in less than 3 hours after the process is learned (the performance objective was 2 days).

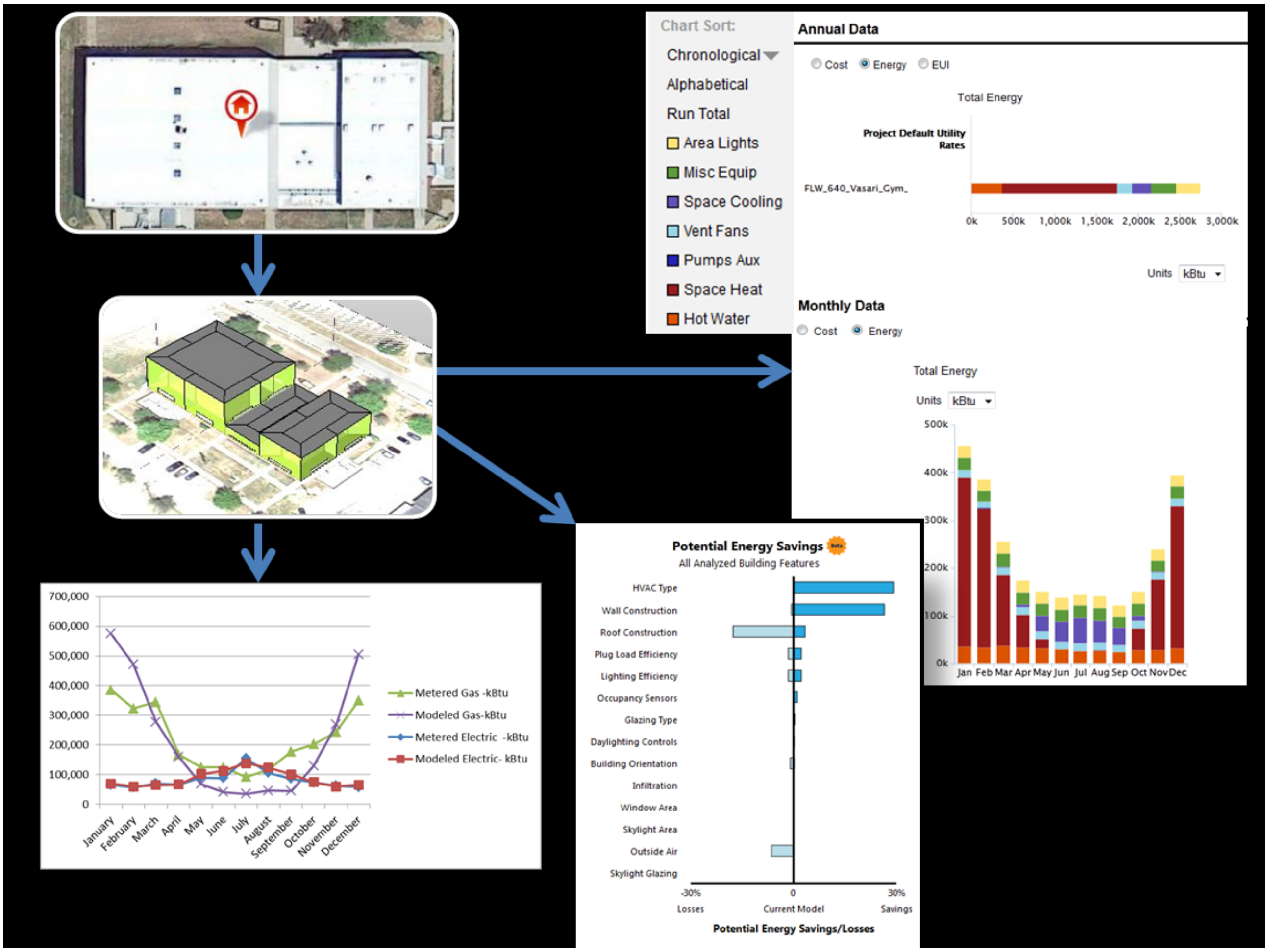
A significant number of considerations were uncovered that help guide the refinement of the REM process in the future, including data gathering and model sensitivity. Additionally, the quality of the DoD building meter data was not as high as expected before the start of this project and as a result, there may be discrepancies in comparison of simulations to the meter data.

While the REM process and reports do not mirror traditional audits, the workflow has potential benefits in that it can be implemented by DoD personnel directly. It is difficult to do a direct comparison to cost or time savings with traditional audits as there is not complete overlap in capabilities, but results indicate that REM can yield >90% savings in time and cost compared to traditional ASHRAE Level 2 auditing approaches, with the added benefits of computer simulation characteristic of Level 3 audits. REM analysis can be completed in less than one hour, with up to two additional hours that may be required for data collection. The modeling process requires minimal training or expertise and has been taught to DoD staff in less than one day during this demonstration project.

The results of this study indicate that REM can scale to help meet the need for EISA 2007 data reporting requirements as well as support government policy including Executive Order 13423. REM provides the DoD with a way to quickly establish building geometry, scale energy analysis of the existing building portfolio, visualize end-use breakdowns of energy consumption, compare tradeoffs and potential energy savings between energy conservation measures automatically, identify facilities that are in greatest need of improvement, and enhance scalability of energy evaluations and retrofits.

Quantitative Benefits	**Average Accuracy Comparison to Historic Utility Information**
EUI Electric Average	81.88%
EUI Natural Gas Average	58.20%
Combined Energy Use Intensity Average	77.56%
Application of Design Alternatives to Model Potential Energy Savings	Energy savings greater than 30% achieved on 3 out of 5 buildings.
Time and Cost to Create Energy models	Cost savings of over 95% and Time savings of 90-95% compared to ASHRAE Level 2 audit
Qualitative Benefits	**End User Effort**
Ease of Learning REM Process	Less than one day
Effort to Create a Rapid Energy Model	3 hours per building with added benefit of auto-generation of multiple simulations to explore and prioritize ECMs

Figure 1-Schematic Workflow of REM Process



The REM Workflow (from top left): Capture Satellite Image, Generate Geometry Model, Produce Anaylytical Reports

1.0 INTRODUCTION

1.1 BACKGROUND

Current building energy assessment methods for existing buildings are expensive, laborious, time consuming and require a high level of technical sophistication, experience and expertise that takes years to establish. In short, typical building energy assessment methods are not scalable across a large number of buildings.

The energy consumed by facilities owned and operated by the U.S. Department of Defense accounts for approximately 80% of the total energy used by Federal buildings (DoD, 2005). However, determining information about the energy use on military bases is challenging, as buildings have historically not been metered individually. Due to data quality issues and lack of access to information, facility managers or resource efficiency managers have difficulty managing their building energy footprints and prioritizing their energy retrofit budgets effectively.

The Department of Defense (DoD) energy success is measured against mandated goals for energy reduction and sustainable facility management. In order to make consistent and well-informed decisions across its entire portfolio of buildings, DoD has a critical need for a consistent, scalable approach for evaluating energy consumption of existing facilities, to compare tradeoffs between energy conservation measures, and to identify facilities that are in greatest need of improvement.

Evaluation of baseline energy use and identification of opportunities for improved building performance are top priorities for decreasing carbon emissions, reducing energy costs and enhancing energy efficiency. Additionally, energy security and regulatory mandates are key drivers of energy efficiency retrofits across the DoD. Typical approaches for rapidly assessing and benchmarking energy usage and evaluating proposed energy retrofit measures are not precise and often fail to acknowledge the complexity of buildings and building performance. Interrelated factors, such as building orientation, location, operational use, and structural idiosyncrasies can all influence energy use and the effectiveness of retrofit decisions on reducing energy usage and energy costs. More comprehensive energy auditing techniques, such as ASHRAE level audits are costly, time-intensive and require a high level of expertise.

To address these challenges, Autodesk executed a demonstration of Rapid Energy Modeling (REM) workflows that employed building information modeling (BIM) approaches and conceptual energy analysis. The project investigated the hypothesis that REM is a viable and scalable method for generating accurate, rapid and cost-effective estimates of energy consumption for DoD buildings. The demonstration was a pilot-scale operation over a one-year period using a population of 35 buildings and an analyzed sample of 23 buildings.

The benefit of this technology is that it puts a viable building energy assessment method in the hands of DoD installations. On-site personnel can reasonably learn and use this approach to prioritize the energy management decisions needed at their installation. This technology can dramatically decrease the time it takes to understand the energy performance of DoD buildings.

1.2 OBJECTIVE OF THE DEMONSTRATION

The project's objective was to investigate REM to determine if the workflow is capable of producing useful, rapid and cost-effective estimates of energy consumption for DoD buildings. REM would then provide the DoD numerous benefits, including the ability to prioritize energy efficiency retrofit projects, track energy use reductions, and manage facilities in new and cost-effective ways.

The overarching objective of the field demonstration was to provide lightweight Building Information Models (BIMs) and an easily scalable REM methodology for estimating energy intensity in DoD buildings, identifying buildings that would be most responsive to improvements and exploring various Energy Conservation Measures (ECMs) for buildings. The motivation is to provide the DoD with an enhanced understanding of how to utilize the REM technology to help the DoD meet federal mandates, reduce costs and increase energy security.

The technology demonstrated included a workflow for creating digital, 3D models of buildings from publicly available satellite or aerial imagery. The process captures existing building geometry, appends operational characteristics as well as local weather data to generate 3D models to estimate the energy use of the modeled buildings. A subset of buildings in this study also demonstrated the technology to apply energy conservation measures (ECMs) to the REM models to provide recommendations on ways to improve the energy performance of the studied buildings.

The research objectives in this demonstration include a comparison of the REM generated energy use simulations to historical metered data. This validation was carried out to provide confidence in the REM methodology. Also validated are the time and cost to produce results with this REM approach as well a comparison of cost requirements for other approaches such as energy auditing. In addition, this demonstration validated the acceptance and use of the REM technology by DoD personnel at installations.

1.3 REGULATORY DRIVERS

The following existing or anticipated federal, state, or local regulations or DoD directives have resulted in a need for a new technology such as REM:

- *Energy Policy Act* (2005) - Requires that *"all federal buildings shall, for the purposes of efficient use of energy and reduction in the cost of electricity used in such buildings be metered … to the maximum extent practicable."* While this mandate has stimulated meter installation on some large existing buildings and newly constructed buildings, the majority of installation buildings are still without individual meters due to cost-effectiveness barriers. Additionally, the Office of the Secretary of Defense has established that only buildings with an estimated electrical usage of at least $35,000 annually are practical / cost effectiveness to meter (DoD, 2005). Without knowledge of baseline energy use in individual buildings, it is difficult to determine which buildings to meter or to evaluate energy conservation measures. REM processes can help the DoD evaluate and benchmark energy utilization in buildings, assist in determining which buildings are practical to meter, identify buildings with meters that are not functioning

well, identify poorly performing buildings and provide the tools to evaluate measures to improve energy efficiency and enhance energy security.

- *Energy Independence and Security Act of 2007* (EISA 2007) - Sets a target for the government to reduce its energy and other resource consumption by 30 percent by 2015 compared to a 2003 baseline. Additionally, EISA calls for energy and water audits for 25% of facilities annually and all appropriate facilities on a four-year cycle. (AEMR, 2010) Using REM processes, the project team conducted rapid audits of DoD buildings and investigated energy conservation measures to achieve reductions in energy use on a subset of five buildings.

- *Executive Order 13423 Strengthening Federal Environmental, Energy, and Transportation Management* (2007) - Encourages continuous improvement in the areas of energy efficiency, renewable energy, water conservation and sustainable building. Models produced through the REM process can be updated and accessed continually, thus allowing energy managers to continuously explore improvements in efficiency and opportunities for renewable energy production.

- *Guiding Principles for Federal Leadership in High Performance and Sustainable Buildings*- Calls for 30 % reduction in energy costs for new construction and 20% reduction in major renovations. REM processes can be used to investigate renovations to meet these energy cost reduction targets and provide a higher level of customization than benchmarking without the time and cost associated with ASHRAE or investment-grade energy audits.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

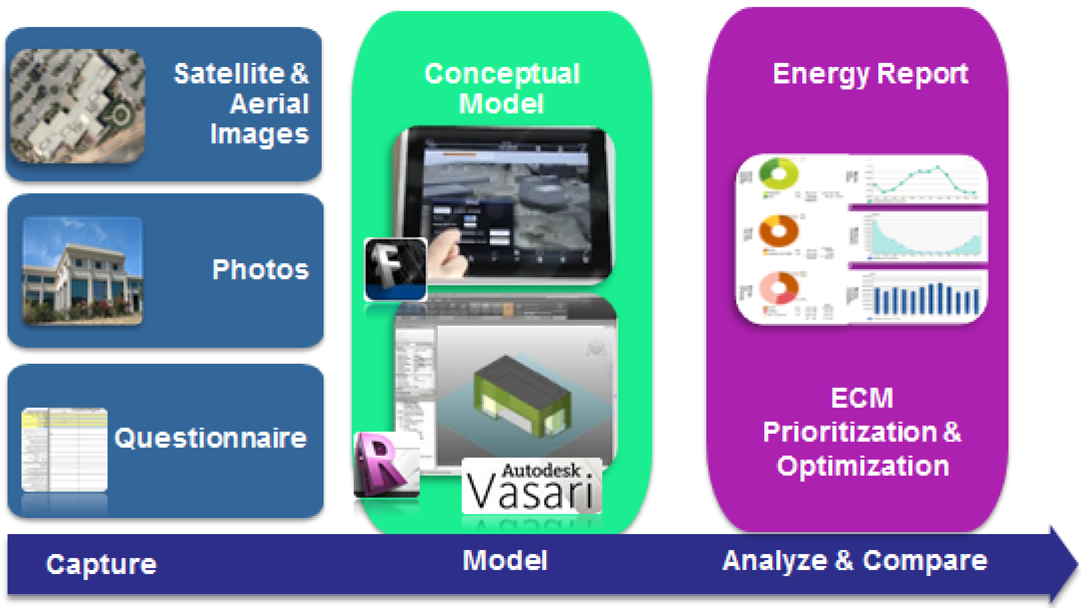
The demonstration defines a process to capture existing building geometry using satellite photos. The operational characteristics of the building are appended to the geometric model and local weather data to generate energy models that can quickly predict the energy use of the modeled buildings. This information can help asset managers determine which buildings are performing poorly compared to predicted energy use.

The REM process involves the following technologies (Figure 2):

- Autodesk® FormIt software is an iOS and Android operating system application to create 3D models. FormIt captures existing building conditions using satellite images from Google and allows users to create a 3D geo-referenced building model while in the field.
- Autodesk® Revit is a Building Information Modeling (BIM) software application with integrated energy and carbon analyses driven by Green Building Studio and DOE 2.2.
- Autodesk® Vasari software is for creating building conceptual models, with integrated energy and carbon analyses driven by Green Building Studio and DOE 2.2.
- Autodesk® Green Building Studio is a web service that performs whole building energy analysis using the DOE-2.2 engine.

The REM workflow involves three stages involving (1) capture of existing conditions, (2) conceptual modeling of building masses using FormIt, Revit and Vasari, and (3) comparative analysis. The energy results of these building analyses are represented as annual energy use for natural gas and electric, monthly and annual cost, monthly energy use and energy use intensity (Figure 2).

Figure 2-REM Technology Components



2.2 TECHNOLOGY DEVELOPMENT

REM began as an idea generated by the Autodesk Sustainability Solutions Team. As early as 2009, a concept paper was written by Autodesk and ICF International defining what could be done with the then current software technologies to provide a less resource intensive way to understand, analyze, and estimate building energy consumption. It is here that the connection of the public satellite imagery to lightweight 3D models to whole building energy analysis is considered; resulting in a new combinational use of these technologies.

That report summarized the results of an in-house experiment at Autodesk, where Autodesk products were applied to Autodesk's own facilities. ICF and Autodesk worked together over the span of three months to test solutions for rapid energy modeling on six Autodesk facilities and investigate the application of Autodesk tools in the wider architecture community. While the rapid energy modeling workflow can be applied to both new and existing building projects, the focus of that study was on existing buildings, both to address a much-needed demand and to validate the models using actual energy consumption data.

In 2011 a white paper was released by Autodesk, giving additional detail to the original REM concept, and discussing new and emerging aspects of the various technologies that were

becoming available. This second paper provided additional details on the workflow as well as customer testimonials and pilot results.

This ESTCP demonstration project focused on this new and innovative workflow applied using the REM component technologies. This project utilized the field demonstration as a rigorous test environment for the methods, procedures and technology envisioned in the concept papers.

Separate from the development of the workflow as a “technology”, REM utilizes several software solutions with separate heritage and chronologies. The first technology is the utilization of publically available satellite imagery collected from services such as Bing or Google Maps. This imagery is used to generate building “footprint” areas of a studied building. Terrestrial digital imagery was investigated as a potential source for building geometry creation but this method proved unsatisfactory for this application.

The next class of technology used for this project is 3D geometric modeling applications. These include Revit, FormIt, and Vasari software applications. These 3D modeling tools provide flexibility to cover the variety of circumstances found at installations and take into consideration the level of experience with the installation personnel.

Revit has a 10-year history creating construction documentation for the building design industry. The basic benefit of the Revit technology is that with this 3D geometric modeling tool, volumes are created when buildings are modeled. In addition, information such as material types can be applied to the model. These capabilities allow for the data for energy modeling (a new use case) to be added to the 3D model and analyzed.

Vasari is also a 3D modeling tool but is designed for conceptual building design models and is easier to use than Revit. Vasari is “beta” software. It integrates energy modeling and analysis features into a geometric/parametric- modeling software application.

FormIt is the third 3D modeling tool tested for this project. FormIt allows for the creation of building models in the field using an iOS or Android tablet.

The final class of software is the energy modeling software Green Building Studio (GBS), which is based on the DOE-2.2 building energy simulation engine. This application utilizes weather station data, generates whole building energy analysis reports, populates analysis results into a user’s GBS online account for further analysis, and creates multiple automatic simulations exploring potential energy saving across multiple building parameters. GBS has been on the market for nearly ten years, and utilizes an XML data file format called Green Building XML (gbXML) for its data inputs.

The summary of these development efforts is that a collection of off-the-shelf software with emerging best practices are providing the potential to simulate the energy use patterns of large numbers of buildings cost effectively.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

Current methods and high costs for energy audits may limit their practicality for implementation across the DoD, and less expensive benchmarking approaches such as Energy Star and CBECS do not provide building-specific detail or identify opportunities for savings.

Alternative technologies include several energy modeling graphical user interface front ends to generate building geometry and apply energy modeling attributes. It was beyond the scope of this project to understand the relative technical merits of these applications. Several of these alternatives are available from the DOE (NREL, 2013).

The REM workflow for energy assessments can provide advantages by offering a level of detail not obtained through benchmarking and with significantly less cost than energy audits. A limitation is that Rapid Energy Modeling (REM) does not provide the detail of investment grade energy audits and does not cover some aspects of a Level 2 energy audit (such as equipment inventories and estimating costs for ECMs), although it does include computer simulation often part of Level 3 audits. The detailed attributes typically required for the Level 1 or 2 energy audits are not based on an understanding of the relative sensitivity of these attributes to energy model performance, so it is difficult to say how much of a limitation it is to simply allow some attributes to be defined with default values. Where full data for the building is not available, intelligent defaults are used based on ASHRAE, extensive background from CBECS, research papers and expert systems developed by energy modeling professionals.

REM is useful in developing a starting point in understanding how the studied building is operating using a model derived from a large set of existing buildings that are operating correctly. Having an understanding of the building energy sensitivities and how building energy use differs from typical buildings allows one to focus the energy conservation work; evaluators can look at their portfolio to find outliers; or users can use prioritize retrofit budget where it is needed most.

Several inputs to the energy model are driven by observations from satellite/aerial imagery and survey responses from building managers. Building and operational attributes of a particular building not properly identified can impact modeling results. This is not a limitation with REM, but a general limitation with simulation in general.

Accurate modeling of building systems is an important factor in developing useful energy models. The downside to focusing on these building systems and their operation is that they add a high level of detail to a process whose goal is to remain rapid and agile. Engineers and energy analysts who want to do more detailed analyses can move REM data to eQuest or EnergyPlus for detailed work in those tools, which may require more expertise and detailed inputs. Constructing the initial model using REM can yield substantial timesavings versus initial model creation in eQuest or Energy Plus tools (Schneider, 2011).

Whole building conceptual energy analysis models provide benchmark building performance for similar buildings in the same climate. The benchmark results are generated based on the basic operational and building design inputs for those attributes know about the building or smart defaults based on the building model type, size and location.

Comparison of modeled and metered results to CBECS revealed that model estimates were much closer to CBECS values, indicating that the differences in the actual building performance were likely due to unique use patterns or poor operation of the buildings rather than incorrect energy model settings. For instance, several POCs indicated that their HVAC systems and boilers are not operating or scheduled correctly, and this may be the cause for the discrepancies; this points to one of the strong values of REM for identifying performance improvement opportunities quickly.

As an update to the demonstration plan and as described in Section 8, Implementation Issues, the quality of the meter data on DoD installations was generally less than was expected by the project team before the start of this demonstration project. This likely led to discrepancies in the comparison of actual and simulated energy use as well.

3.0 PERFORMANCE OBJECTIVES

Table 1-Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Correlation of REM with Annual Energy Electricity & Fuel Intensity	kWh and therms	Utility history and/or energy meter data (compared to gbXML model data)	Annual Electric and Natural Gas Energy +/- 10% compared to baseline historical utility data Annual Electric and Natural Gas within good to reasonable prediction levels as defined in literature.	-Results were within 10% error on 7 out of 25 buildings for electric. Two buildings fell within +/-10% for natural gas. Overall, there was 81.88% average accuracy for electric (18.12% mean absolute percentage error). -Models for electric use in office buildings performed better than models for barracks or specialty use buildings, with 85.70% average accuracy (14.30% mean absolute percentage error). Accuracy for natural gas averaged 58.2% (41.80% MAPE). -Principle reasons for deviations could be related to flawed meter data, weather anomalies, occupancy variations in building usage, or interior space utilization differences (see 8.0). -Also, deviations may point to operational inefficiencies that should be addressed through re-commissioning for energy and cost savings.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
				-Although not within 10% error, electric mean absolute percentage error values were within the 11-20% threshold, considered "good". Forecasts of natural gas usage at 41.80% MAPE were within 21%-50%, considered reasonable (Lewis, 1982; Chet et al. 2008)
Correlation of REM with overall Annual Energy Use Intensity	kBtu/ ft²	Utility history and/or energy meter data (compared to gbXML model data)	Annual Energy Intensity +/-25% compared to baseline historical utility data Annual EUI predictions within good to reasonable levels as defined in literature.	-14 out of 25 buildings were within +/-25% MBE in predicting overall EUI. Average accuracy was 77.56% (MAPE of 22.44%) -MAPE results fall within the 21%-50% threshold, considered reasonable. As above, deviations may be related to inaccurate meter data, operational inefficiencies, weather anomalies, or space utilization.
Variance in Monthly Consumption (Billing History)	%	Utility rates, energy meter data and modeled energy data for each building	Acceptable values are a Coefficient of Variation of the Root Mean Squared Error (CV(RMSE)) of $\leq$ 15%.	-Results were within 15% CVRMSE for 3 buildings using billing history and cost as metrics. An additional 2 buildings were within 20% CVRMSE. -Additional simulation runs did not attempt to tune the modeled results to match metered values, but the CVRMSE provides a snapshot of how baseline models aligned with metered data. - It was not anticipated that initial models would align within 15%, as this is the standard that calibrated models are working towards and is outside of REM intent. Buildings with the closest calibration were selected for exploration of design alternatives for energy conservation measures.
Testing the REM process for Design Alternatives to Model Potential Energy Savings	% energy savings in kWh and therms	gbXML file and Green Building Studio design files	Design strategies will attempt to achieve energy savings greater than 30%	-ECMs explored basic and advanced design strategies for 5 buildings. Savings greater than 30% was achieved on 3 out of the 5 buildings. -The two buildings that did not achieve the target already had undergone energy retrofits, which were reflected in the models.

Qualitative Performance Objectives				
Performance Objective	**Metric**	**Data Requirements**	**Success Criteria**	**Results**
Ease of learning technology and expertise required	Person hours of training to complete building model	Training Curriculum	On average less than 6 days to learn technology and complete 1st building model and generate an energy report	Training completed to data indicates that DoD participants can learn the workflow and begin creating and analyzing in less than one day.
User Satisfaction	Satisfaction with REM workflow and processes	Responses from informal interviews and anecdotal observations	Users are generally satisfied with the REM process, tools, and results	Participants indicate a high level of satisfaction with the workflow.
Ease of use creating REM models	Number of hours to complete model and generate predicted energy consumption reports after process has been learned.	Hours required for successful completion of REM training program.	After successful completion of first REM on average less than 2 days per building to complete model and generate reports	The one year of technology transition has not yet passed, however preliminary results indicate that energy models can be completed in less than 3 hours after the process is learned.
Ability to scale process across the DoD	Number of REM trained personnel at end of pilot study	Participants active in training program and completion of training	Five individuals trained and independently creating REM models at completion of first year of technology transition.	At this point in time, 3 individuals have received training, with others scheduled for training in the future.

3.1 QUANTITATIVE PERFORMANCE OBJECTIVES

3.1.1 Correlation of REM with Annual Energy Electricity Intensity

- This objective sought to use REM workflows to estimate electricity intensity and then compare estimates with actual electricity intensity from utility meter. Performance was measured using a metric of kWh and electric kBtu per ft². Utility history and/or energy meter data was required; the meter data was held blind by ERDC-CERL and not released to Autodesk until after modeling and simulation were complete at which point the modeled estimates was compared to utility data.
- Results were analyzed using direct comparisons of annual electric data and reported through tables, charts and graphs. Plotting measured and predicted (modeled) monthly data values allows identification of periods that have the largest mismatch between estimated and measured energy values.
- Autodesk defines success as being able to estimate annual electricity energy usage within +/-10% error.

- This success metric is based on the assumption that meter data was accurate and normal weather conditions existed. The ESTCP project identified numerous issues with individual building meters that resulted in the exclusion of some buildings. Additionally, some buildings that were included in the study had periods of questionable data, evident in extreme spikes and drops in meter readings.
- Deviations can assist with portfolio analyses by helping to identify outliers, low hanging fruit, and buildings with operational inefficiencies which should addressed through retrofits
- Results were analyzed on an overall and an individual building basis, as well as aggregated by building type. Mean Bias Error (MBE = (Modeled-Measured) / (Measured) was used as a metric to evaluate individual building results compared to annual baseline historical meter data; performance objectives defined +/-10% error as the desired threshold. Lewis (1982) is often cited as a method to evaluate the accuracy of predictions, wherein 11%-20% is a good forecast, 21%-50% is a reasonable forecast, and 51% or more is an inaccurate forecast (Lewis as cited in Chen, 2008) (Table 2).
- Mean Absolute Percentage Error (MAPE) was calculated using the sum of the absolute percentage of error for aggregated buildings divided by the sample size. As a rule, the lower the MBE and MAPE values, the more accurate the model forecast. Standard deviations, coefficient of variations, mean absolute deviation (MAD), mean square error (MSE), and mean frequency error (MFE) were also documented.

Table 2-Typical Mean Absolute Percentage Error Values for Model Evaluation

MAPE (%)	Evaluation
MAPE $\leq$ 10%	High Accuracy Forecasting
10% $<$ MAPE $\leq$ 20%	Good Forecasting
20% $<$ MAPE $\leq$ 50%	Reasonable Forecasting
MAPE $>$ 50%	Inaccurate Forecasting

Source: Lewis (1982).

3.1.2 Correlation of REM with Annual Energy Natural Gas Intensity

- This objective sought to use REM workflows to estimate natural gas intensity and then compares estimates with actual natural gas intensity from meter data.
- Performance was measured using a metric of natural gas MMBtu and kBtu per ft^2.
- Performance and success criteria are the same as referenced for electric intensity above.

3.1.3 Correlation of REM with Annual Energy Use Intensity (EUI)

- This objective used REM workflows to estimate overall Energy Use Intensity (EUI) then compares estimates with actual EUI intensity from combined electric and natural gas meter data held by CERL.
- Performance was measured using a metric of kBtu per ft^2 and success was defined as the ability to estimate energy usage within +/- 25% error compared to baseline historical meter data for individual buildings. MAPE, MBE were the primary metrics used to evaluate success. Additionally, Standard deviations, coefficient of variations, mean absolute deviation (MAD), mean square error, and mean frequency error were documented.

3.1.4 Variance in Monthly Consumption (Billing History)

- ASHRAE felt there was a need for a consensus framework that can be used to calculate normalized savings that adjusts for non-energy conservation measures that can influence energy use. Billing information was not available, therefore electric and natural gas usage from building meters and utility rates provided by installation POCs were used as a proxy. Results were analyzed using direct comparisons, charts and graphs.
- Acceptable values are a Coefficient of Variation of the Root Mean Squared Error (CV(RMSE)) of less than 15%. It should be noted that while models were compared to actual metered usage, then were not tuned or re-run to match metered usage, and this is outside of the scope of the Rapid Energy Modeling workflow. Rather, the CVRMSE calculation provides visibility into how close initial monthly modeled values are to calibration with monthly metered values.

3.1.5 Testing the REM process for Design Alternatives to Model Potential Energy Savings (PES)

This objective investigated energy conservation measures or strategies within Green Building Studio for a subset of five different buildings. Performance was measured using a metric of percentage energy savings for natural gas and electric individually, percentage reduction in EUI and cost savings.

- Selection of ECMs was guided by Potential Energy Savings (PES) analyses within Green Building Studio and will explore potential savings with different ECM packages: a basic package that does not include building envelope improvements and an advanced package that includes basic package measure but also includes more costly envelope improvements.
- Results were analyzed using comparison of the approaches and reporting the results through charts, graphs and standard deviations. Energy conservation strategies attempted to demonstrate energy savings greater than 30% (per EISA 2007 Whole Building Energy Reduction Targets).
- Results are displayed for both the simulation results and the baseline from meter data.

3.1.6 Time and Cost Effectiveness for Energy Modeling

- The objective investigated time and cost required for Rapid Energy Modeling to ASHRAE Level 2 audits. Performance was measured using a metric of hours and cost per building and per square foot. Comparisons referenced published information on ASHRAE Level 2 audits. Reported costs for detailed energy audits varied from $0.12 up to $0.50 per square foot, depending on the size and complexity of the building. (Baechler, et al. 2011). For the purposes of this study, researchers used the low-range estimate.
- Results focus on calculations of time and cost savings of REM compared to audits, with an emphasis on improved scalability for DoD.
- The performance objective attempted to demonstrate a >30% improvement in time and cost savings compared to typical auditing approaches, with the understanding that REM is not to be considered as a replacement technology to ASHRAE audits.

3.2 QUALITATIVE PERFORMANCE OBJECTIVES

3.2.1 *Ease of Learning Technology and Expertise Required*

- DoD personnel were trained on REM technology using training curriculum developed during this demonstration project. The target audience was installation energy managers or other staff; there was no prior experience with energy modeling technologies required.
- The objective of the initial training session was to get the average participant to learn the software solutions, understand the steps needed to incorporate the recorded data, complete the first building model and generate results from the analysis.
- The ease of learning the REM technology curriculum was measured in person hours.
- Results were analyzed using documentation of level of effort for each participant. It was anticipated that, on average, it will take less than 6 days for personnel to learn the REM technology, complete the 1st building model and generate reporting results.

3.2.2 *User Satisfaction*

- The purpose of this objective was to get feedback from DoD personnel that received training on the REM workflow and includes responses from informal interviews, a formal survey of training attendees and anecdotal observations.
- Upon completion of training, users were asked about their satisfaction with REM workflows, tools and processes. It was anticipated that the majority of users would be satisfied with the REM process, tools and results.

3.2.3 *Ease of Use Creating REM models*

- The purpose of this objective was to assess REM workflow ease of use.
- Researchers with only one day of prior conceptual energy modeling experience documented the number of hours to complete model and generate predicted energy consumption reports after process was learned and recommend optimized workflows based on lessons learned, and requirements for inputs, model outputs, time, and expertise.
- Results are presented as a decision matrix to communicate attributes of various workflows, and guide users to the most appropriate software given their capabilities and requirements.

3.2.4 *Ability to Scale Across the DoD*

- The purpose of this objective was to assess the ability to scale the REM workflow across the DoD and will be determined by the number of REM trained personnel at end of pilot demonstration period. Researchers will have five individuals trained and independently creating REM models within one year of technology transition.

4.0 FACILITY/SITE DESCRIPTION

4.1 FACILITY/SITE LOCATION AND OPERATIONS

Port Hueneme is located within Naval Base Ventura County (NBVC), covers more than 6000 acres and is located approximately 60 miles northwest of Los Angeles, California. Port Hueneme contains one of the few deep-water ports on the West Coast. NBVC Port Hueneme is home to the Pacific Seabees, four Naval Mobile Construction Battalions, Underwater

Construction Teams, the Naval Surface Warfare Center, Naval Facilities Engineering Service Command and Naval Facilities Engineering Logistics Command. Other facilities within NBVC include Point Mugu and San Nicolas Island. Altogether the facilities within NBVC have a base population of more than 17,000 personnel, making it the largest employer in Ventura County (VCNavBASE). This installation indicted that electric and natural gas data was available for 4 buildings but natural gas data was only available for one building; the other three buildings were modeled but were not included in pooled analysis.

Naval Station Great Lakes is located near North Chicago, Illinois. The base is the largest training station in the Navy and the Navy's only bootcamp. Each year approximately 38,000 individuals complete Navy enlistment requirements at Naval Station Great Lakes. (NSGreatLakes) The base has 1,153 buildings situated on 1,628 acres. All three buildings sampled at Naval Station Great Lakes were district steam which Green Building Studio cannot analyze; these buildings were modeled but not included in pooled analysis. One building (7103) is actually three buildings sharing common walls with one electric meter and one steam meter. Building 800 is a series of 7 separate dormitory buildings sharing one electric meter and one steam meter.

Naval Surface Warfare Center, Panama City is located on 650 acres along the Gulf of Mexico in Panama City, Florida. The base is a leader in amphibious warfare systems, mine warfare, mine systems, countermeasures and military diving. The base employs approximately 2,000 civilian and military personnel and has 221 buildings. (PanamaCityInfo)

Naval Weapons Station Earle, is located in Colts Neck, New Jersey and Middleton, New York. The base provides all ordnance for all Atlantic Fleet Carrier and Expeditionary Strike Groups. The base encompasses approximately 12,000 acres and employs a workforce of over 1500 personnel. (NWSEarle) Models results and analysis for this installation are included in Appendix C, however there were apparent scaling issues identified by researchers and acknowledged by the installation POC; these buildings were not included in pooled analysis.

Portsmouth Naval Shipyard is located on over 297 acres in Kittery, Maine, across the harbor from Portsmouth New Hampshire. The base is one of four shipyards in the nation, and provides overhaul, repair and modernization of the Naval submarine fleet. The base employs approximately 4800 employees, including 100 naval officers and enlisted personnel. Many of the base's buildings are in a historic district and 50 buildings are listed on the National Register of Historic Places. (Portsmouth)

Fort Leonard Wood Army Base is located on 62,991 acres in Fort Leonard Wood, Missouri, approximately 130 miles west of Saint Louis. Fort Leonard wood is home to Maneuver Support Center, Chemical, Biological, Radiological and Nuclear Schools, Engineer and Military Police Schools, and the Center of Excellence for Homeland Defense. (FtLeonardWood) The base is considered a leading training installation and has a major economic impact on the community, employing over 9000 civilians. (Army2020FLW)

U.S. Army Construction Engineering Research Laboratory (ERDC-CERL), is located in Champaign, Ill. ERDC-CERL directs research to increase the Army's ability to *"more efficiently design, construct, operate and maintain its installations and contingency bases and to ensure*

environmental quality and safety at a reduced life-cycle cost". (CERL) CERL is located within 3 buildings at the University of Illinois at Urbana-Champaign (UIUC) and regularly collaborates with UIUC on DoD initiative. (CERLFactSheet) All three buildings at CERL were modeled and analyzed, however it should be noted that there is only one natural gas meter for all three buildings. CERL energy analysts supplied estimates of individual building metered natural gas usage based on allocation by building size.

Joint Base Lewis McChord is located on over 414,000 acres in the Puget Sound region outside of Tacoma, Washington. The Joint Base provides support to more than 40,000 service members and approximately 15,000 civilian workers. (JBLM) The mission of the base is to provide training, mobilization and deployment operations for Army, Navy, Air Force, and Marines. The base supports a population of over 100,000 individuals and has over 22.8 million square feet of buildings, not including family house. (JBLMBriefing)

Seymour Johnson Air Force Base is located on 3300 acres in Goldsboro, North Carolina. The base supports approximately 12,000 individuals including 4600 active duty and 1000 civilians. The base is home to the 4th Fighter Wing, a distinguished fighter wing within the Air Force that provides aircraft and personnel for executing combat missions. The base also provides technical officer military training for cadets.(SJAFB) The base population is approximately 12,000 including 5600 military members and over 900 civilians. There is approximately 4.5 million square feet of building area.(SJISA)

Peterson Air Force Base is an Air Combat Command base located on approximately 1300 acres adjacent to Colorado Springs, Colorado. The base is headquarters for the 21st Space Wing and is the Air Force's only provider for missile warning and space control to global combat forces (Peterson). The base supports over 6500 military members and approximately 600 civilians (SJUnits) and manages over $400 million in Real Property.

4.2 FACILITY/SITE CONDITIONS

Researchers visited 10 installations and a population of 35 buildings across six climate zones (Figure 4) between December 2012 – March 2013 and selected 23 buildings for inclusion in the core analysis of the study. This includes a total of five Navy bases, three Army sites, one Air Force site, and one Joint Base (Figure 3).

Prior to scheduling the site visits, researchers had received verification that meter data was complete and usable by ERDC-CERL, a partner on this project working via a CRADA set up for this project. Site visits included engagement with the installation POC and review of the completed energy questionnaire. Researchers took the opportunity to ask clarifying questions from the POC and visited the exterior of individual buildings with the installation escort.

The military operations occurring at the selected installation sites varied depending on military sector, installation and building type. The demonstration project did not interact with ongoing operations at the military facilities.

Figure 3-Site Locations

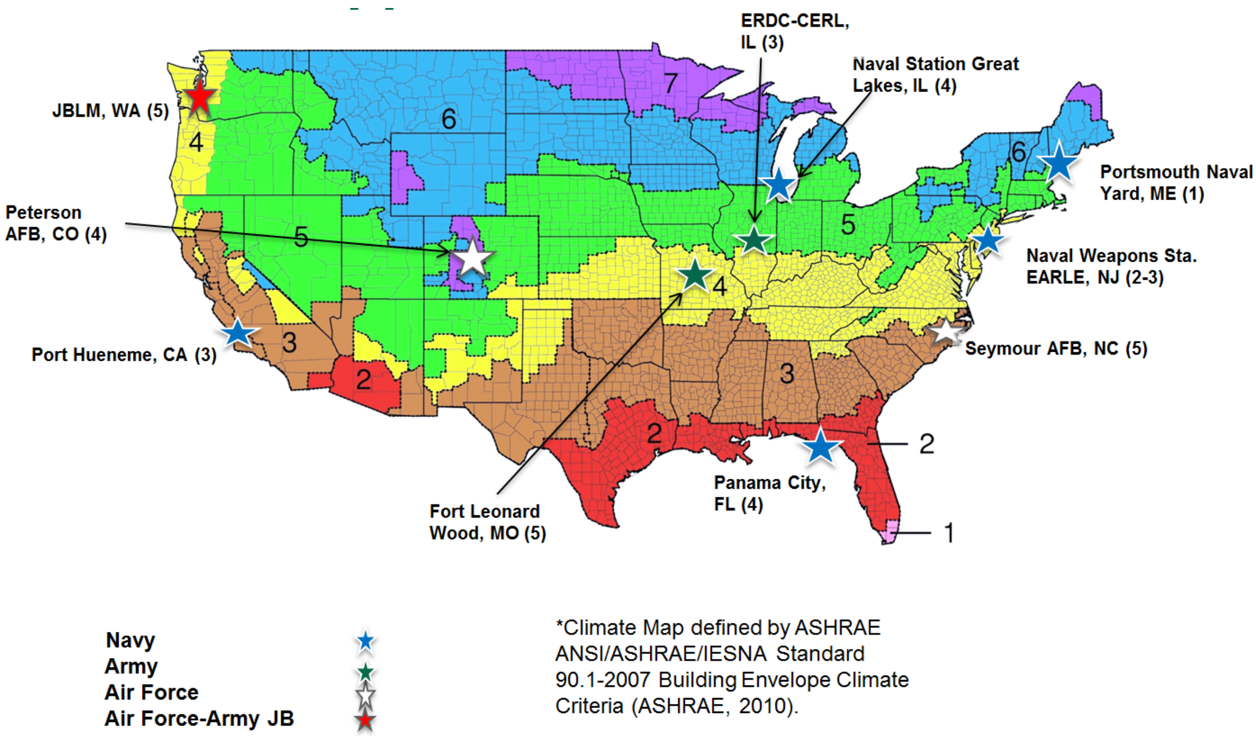


Table 3-Site Information

Installation	Buildings
ERDC-CERL	3 Offices
Fort Leonard Wood	1 Office; 3 Barracks (1 excluded from analysis), 1 Gym
Joint Base Lewis McChord	2 Offices (1 excluded); 2 Barracks (1 excluded)
Panama City	2 Offices; 1 Barracks
Peterson AFB	4 Offices
Port Hueneme	4 Offices (3 excluded)
Portsmouth	1 Barracks
Seymour AFB	1 Office; 1 Cafeteria; 1 School; 1 Fire station; 1 Automotive Facility
Earle Naval Weapons Station	1 Office; 1 Auto Facility; 1 Cafeteria (all excluded)
Great Lakes	2 Barracks; 1 Drill Hall (all excluded)

5.0 TEST DESIGN

5.1 CONCEPTUAL TEST DESIGN

This project evaluated technical performance and cost characteristics of estimating energy consumption of buildings by conducting Rapid Energy Modeling (REM) simulations. These simulations were then compared blindly to historical energy use information of the same studied buildings.

The project utilized the REM methodology on 23 DoD buildings of varying use types across 6 different climate zones. A subset of five buildings was further processed with the design alternatives capabilities of Rapid Energy Modeling software tools in order to estimate how much energy could be saved by applying Energy Conservation Measures (ECMs). Design alternatives were selected for each of the five buildings by the project team and simulation estimates are included in this report. Test phases are described in Table 4.

Table 4-Test Phases

Test Phase	Activity
Reality Capture	Capture - Pre-Installation Phase 1. Identified a population of 35 candidate existing DoD facilities of various types in different locations; reduced the number to 23 buildings for aggregate analysis because of meter data quality concerns 2. Candidate buildings identified on satellite and verified by installation POCs 3. Captured structural, operational and systems information through Installation Energy Questionnaire, including: • Building profile: Location, building use type, age of building, operational schedule • Building geometry: floor height, total building height, gross square footage, window: wall ratio, number of floors and below grade floors, roof and wall construction • Operational parameters: HVAC systems • Structural and Operational Anomalies: Atriums, overhangs, basement storage rooms, refrigeration, elevators, escalators, vending machines, renewable energy sources, data centers o *Note: Building energy variables are typically set to ASHRAE defaults if information is not available* 4. ERDC-CERL collected, verified and retained building energy utility meter data Capture - Installation Phase 1. Visited installation and asked clarifying questions about the submitted energy questionnaire, capture onsite reference photos

Model	Construct BIM-based Building Models Geometry Creation Subtask 1. Used FormIt conceptual modeler in the field to create 3D building model, refined the model in Revit based on energy survey, site observations and reference photos 2. Vasari workflow explored a remote approach using software-integrated satellite imagery and the energy survey Energy Analysis Subtask 1. Generate Energy Models based on conceptual model building location, geometry, energy settings, ASHRAE defaults where energy settings were not provided, and weather information 2. Perform Conceptual Energy Analysis driven by Green Building Studio / DOE 2.2 engine 3. Produce energy reports
Analyze	Analyze Model Results 1. Comparison of modeled results to actual utility meter data 2. Compare metered and modeled energy information to benchmarking results using CBECS 3. Compare REM to time and cost of audits 4. Review the energy analysis findings under the High Performance and Sustainable Building Guiding Principles Compliance Pathways for building efficiency and sustainability goals for CVRMSE, using billing rates to compare monthly meter and modeled results. 1. CVRMSE monthly billing calculations 5. Five (5) of the study’s twenty three (23) buildings that were within an acceptable tolerance of CVRMSE calibration were further processed with the design alternatives capabilities of GBS, informed by PES analysis across a range of building parameters
Technology Transfer	Workshop, Webinar and Curriculum Development
Reporting	Report development and submission

5.2 BASELINE CHARACTERIZATION

The historical metering data was used as a reference condition to determine the technical performance accuracy of the REM method and the existence of historical natural gas and electric metering information was a prerequisite for a building to participate in this study. ERDC-CERL requested building natural gas and electric meter data at the most granular level available from candidate installations. CERL then conducted a review of this data to ensure that at minimum there were 12 months of reliable natural gas and electric meter data for each building.

The inputs for the energy model were derived using imagery and responses to the site survey, and focused on rapid baseline characterization of the building geometry, operations and systems.

The REM workflow also does not utilize floorplans or model interior walls, opting instead for ASHRAE standard perimeter-core space simplification and a maximum width of perimeter zone to minimize the error introduced by removing interior partitions. The REM models also do not designate different space utilizations within a building, so buildings with different space utilizations (i.e. office and lab) are modeled as one building type per generalizations similar to the building-wide defaults recommended in ASHRAE 90.1 vs. the space-by-space method. Accurate modeling of interior spaces is possible with the software tools, however this requires a significant time investment to collect, organize, and translate building plans into the model, and would require additional expertise from DoD end users that is not of sufficient value for the purposes of a REM survey.

Similarly, building schedules may not be uniform throughout the building, or consistent on a weekly, monthly or annual basis. Researchers used information provided by installation staff to determine schedule selection in the modeling and energy analysis tools. Several installations provided monthly totals instead of interval meter data as requested, thus in these cases few insights regarding accuracy of schedule assumptions could be gleaned. It was assumed that weather for the year of meter data submitted was not anomalous.

Some installations submitted monthly interval data, while others submitted 15-minute interval data. Several buildings were eliminated during this validation stage, due to apparent issues with the meter data. Other datasets were validated and included in the study, only to have the meter data later determined to be unreliable when released from CERL to Autodesk for comparison with REM results. Several buildings included in the study have meter data anomalies, such as large spikes in usage that may or may not be accurate (see Appendix D).

Additionally, modeled energy results, and metered data were compared to the US Department of Energy Index for Commercial Buildings, which utilizes data from the Energy Information Administration (EIA) 2003 Commercial Buildings Energy Consumption Survey (CBECS) using the Building Energy Data Book tool. Primary search criteria were climate zone and building type, followed by size and vintage if sample sizes were sufficient (n>10) to allow further refinement.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

Technology components included REM tools (see section 2.1 for description)

Researchers explored the various software tools and workflows to better assess capabilities and then optimize scalability for DoD when technology is transferred. Some of the tools have overlap in terms of their functional attributes, and the portability of file formats between tools allows users a great deal flexibility in determining a workflow (Figure 4 and Figure 5) depending on the level of detail desired, expertise, and time constraints (See Section 6.5 for discussion of attributes of workflows.)

Figure 4-Visual Depiction of Technology Components

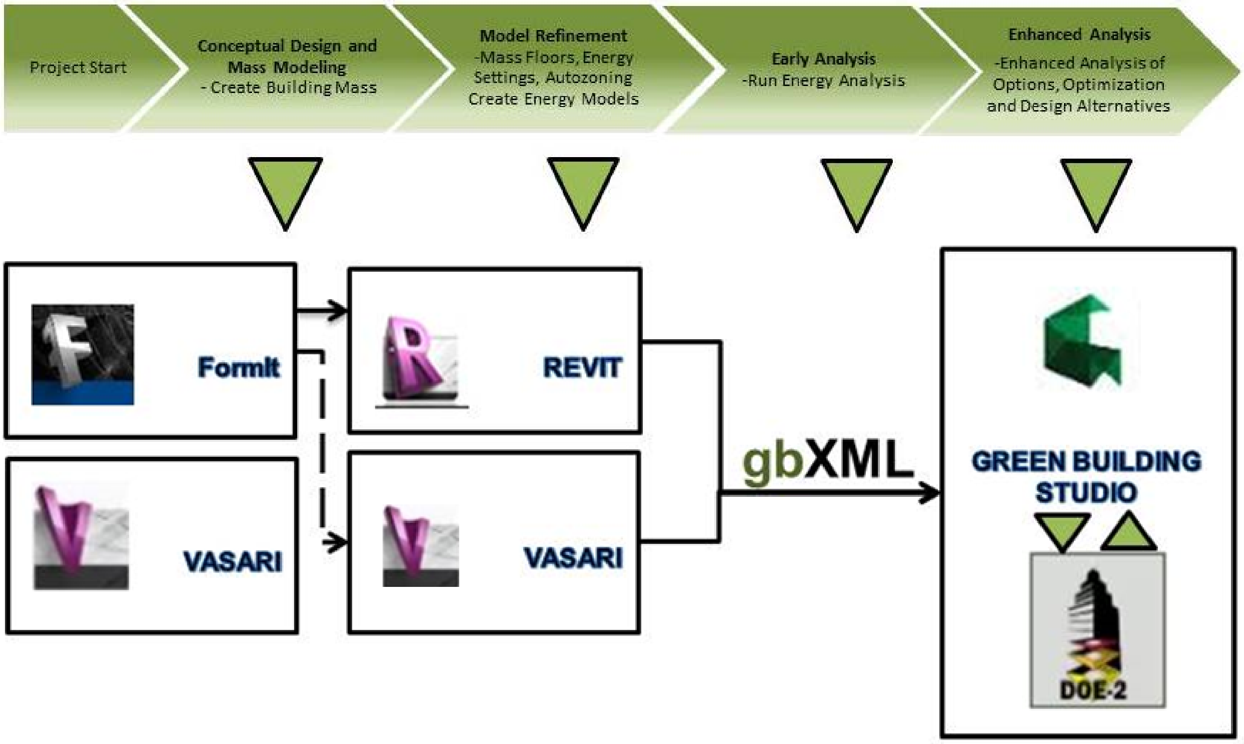
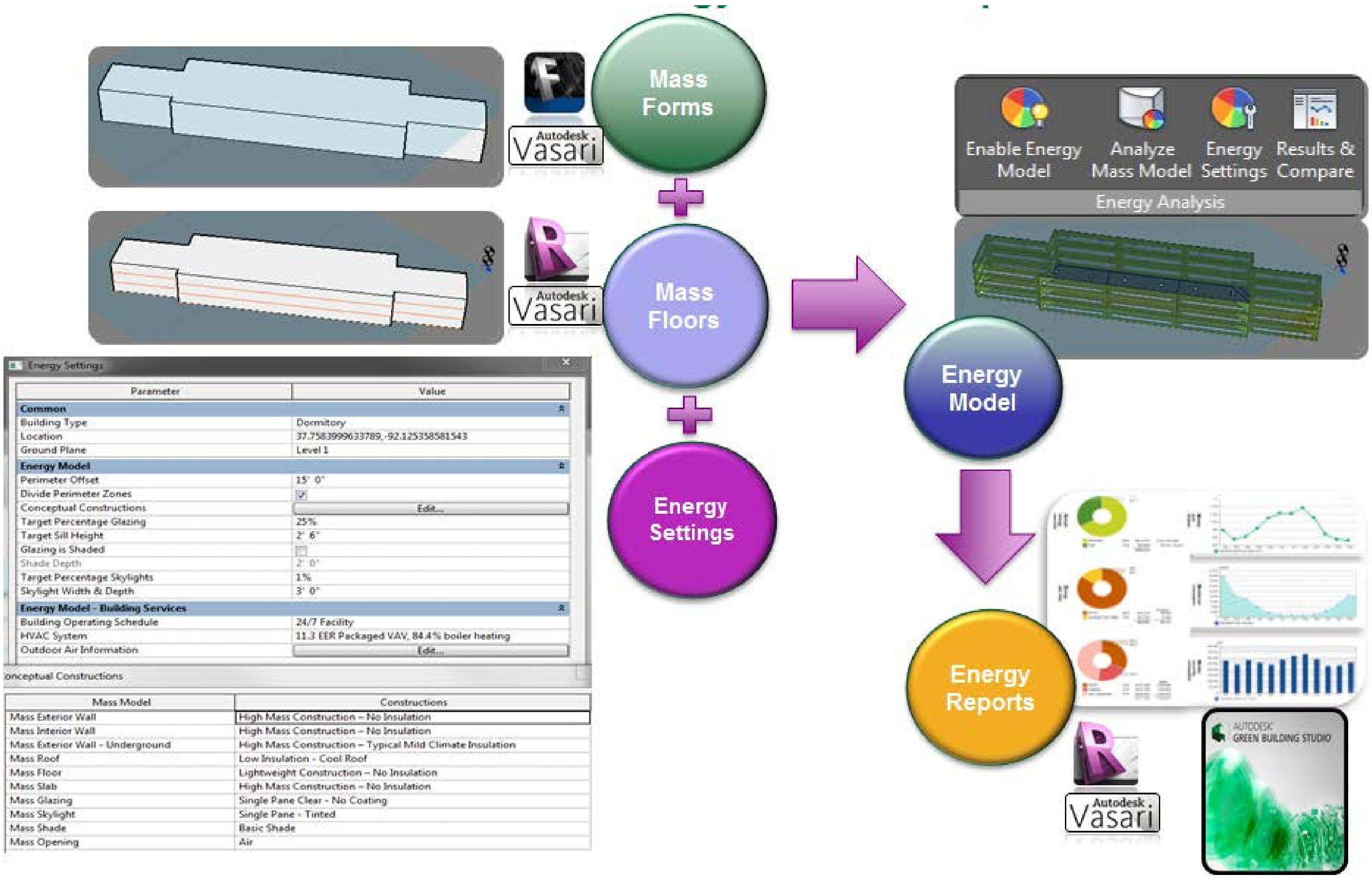


Figure 5-Visual Depiction of DoD Technical Workflow



In the REM workflow, the mass form geometry is created using satellite imagery. Mass floors are then created to reflect the number of levels and floor-to-floor heights of the building, which are informed by the questionnaire responses and satellite images (See section 5.1). Energy settings are then selected based on questionnaire information or satellite information in the case where supplied information is inadequate. The energy model is then enabled and zoning is created based on ASHRAE. The energy model report is then generated in Green Building Studio. Enhanced analysis is then possible with GBS.

Workflows
Autodesk FormIt mobile was used on iPads in the field to create rough 3D building mass form models (Figure 6). This approach allowed teams to identify and model only conditioned spaces, and disregard atriums and overhangs in the models, which were apparent when teams were onsite but not always visible using exclusively satellite images.

Figure 6-FormIt Model Creation

FormIt models were then moved into Revit software, wherein teams calibrated the building size to the gross conditioned square footage indicated in the energy survey, created mass floors to match survey responses and site observations (Figure 5), designated energy settings guided by survey responses and site visit observations (Figure 7) ran energy analyses and created an energy report for each building.

A more streamlined and remote approach using Vasari was used for each building. Like FormIt, Vasari allows the user to easily import a scaled and geo-referenced satellite of a building, and also allows users to reference the nearest weather station (Figure 8). Upon pulling in a satellite image, the research team then used information from the energy surveys, and observations from satellite and aerial birdseye images, such as Bing Birdseye (Figure 9) or Google Streetview to guide energy settings and verify energy survey responses related to wall constructions, glazing ratios, etc.

The research team calibrated models to reported conditioned gross floor area, adjusted building height to match reported height, created floor levels, activated autozoning and ran energy analyses in Vasari.

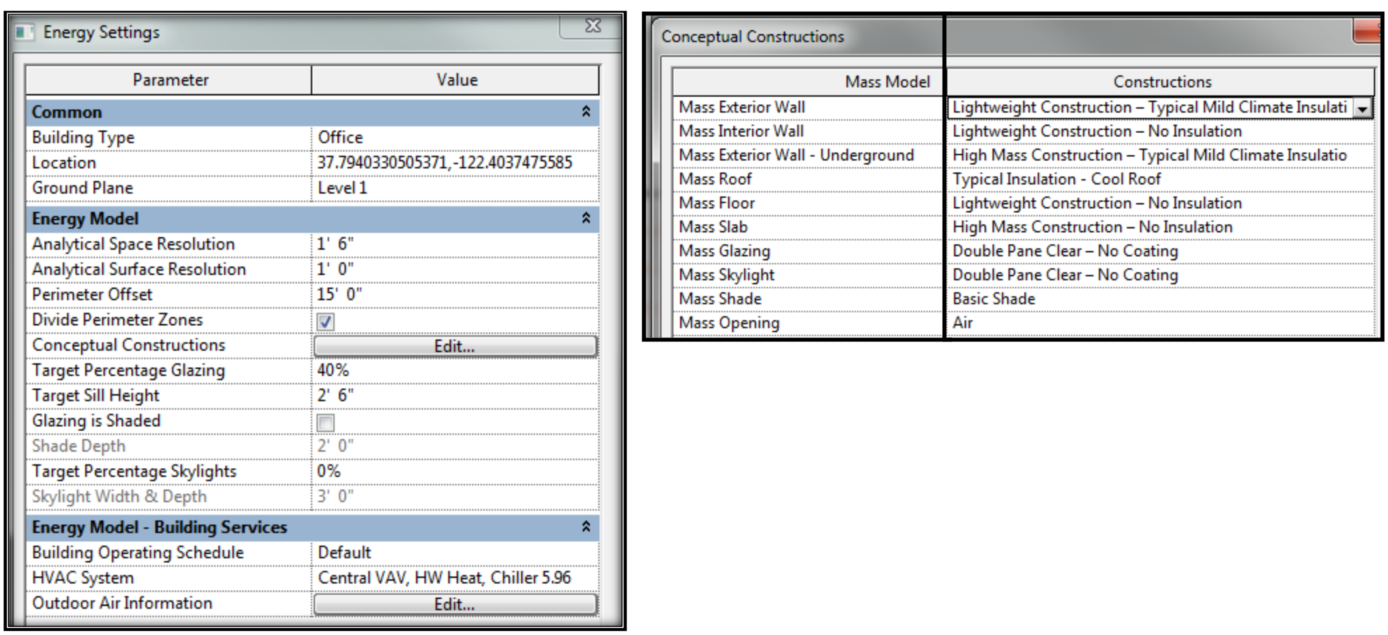
Green Building Studio utilizes the DOE-2.2 engine to run energy analyses and create reports. DOE-2.2 is a whole building hourly simulation program that considers the geometry of the building and its internal spaces, construction, equipment, and hourly operation schedules. DOE-2.2 is also the engine behind eQuest, a freeware engineering tool that is one of the most widely used whole building hourly simulations tools in the U.S. today.

Starting with the first hour of the year and for every hour of the year, DOE-2.2 reads in the weather data based on location (temperature, humidity, solar, wind speed and direction, pressure) from the location's weather data file. DOE 2.2 then determines the heating and/or cooling loss or gain from the roof, skylights, walls, windows, and floors as well as calculates the equipment (lights, computers, etc.) running in the building and the heat, light and moisture coming off that equipment and its energy use for that hour, calculate the number of people in each space and the heat and moisture coming off the people in each space for that hour, determines the thermostat set-point for that hour, and calculates the amount of energy the HVAC equipment needs to use for that hour to maintain the thermostat set-point. DOE-2.2 does this for every hour of the year and generates a variety of results including monthly and annual energy use (electricity and natural gas) and cost of the building.

Researchers attempted to get specific information about building construction and operations from installation personnel and applied this information in the energy settings. Some information however was left as defaults, which are based upon ASHRAE standards, including: analytical space and surface resolutions, perimeter offset, sill height, and outdoor air information. Additionally, input defaults used in the energy analysis but not visible in Revit or Vasari Energy settings are also based on ASHRAE standards [(GBS)].

Green Building Studio and the DOE 2.2 engine allow the automatic generation and display of energy reports. The energy reports provide detail on: Energy Use Intensity (kBtu/ ft^2/year), Annual and Monthly Electric, Fuel and Total Energy Use and costs, Detailed Annual Electric and Fuel End Use breakdowns (Figure 13), Carbon Emissions, Estimated Water Usage, PV and Wind Potential, as well as other detailed energy performance information (Figure 10).

Figure 7-Energy Settings with REM tools



Energy Settings

Parameter	Value
Common	
Building Type	Office
Location	37.7940330505371,-122.4037475585
Ground Plane	Level 1
Energy Model	
Analytical Space Resolution	1' 6"
Analytical Surface Resolution	1' 0"
Perimeter Offset	15' 0"
Divide Perimeter Zones	☑
Conceptual Constructions	Edit...
Target Percentage Glazing	40%
Target Sill Height	2' 6"
Glazing is Shaded	☐
Shade Depth	2' 0"
Target Percentage Skylights	0%
Skylight Width & Depth	3' 0"
Energy Model - Building Services	
Building Operating Schedule	Default
HVAC System	Central VAV, HW Heat, Chiller 5.96
Outdoor Air Information	Edit...

Conceptual Constructions

Mass Model	Constructions
Mass Exterior Wall	Lightweight Construction – Typical Mild Climate Insulati
Mass Interior Wall	Lightweight Construction – No Insulation
Mass Exterior Wall - Underground	High Mass Construction – Typical Mild Climate Insulatio
Mass Roof	Typical Insulation - Cool Roof
Mass Floor	Lightweight Construction – No Insulation
Mass Slab	High Mass Construction – No Insulation
Mass Glazing	Double Pane Clear – No Coating
Mass Skylight	Double Pane Clear – No Coating
Mass Shade	Basic Shade
Mass Opening	Air

Figure 8-Satellite Image Import

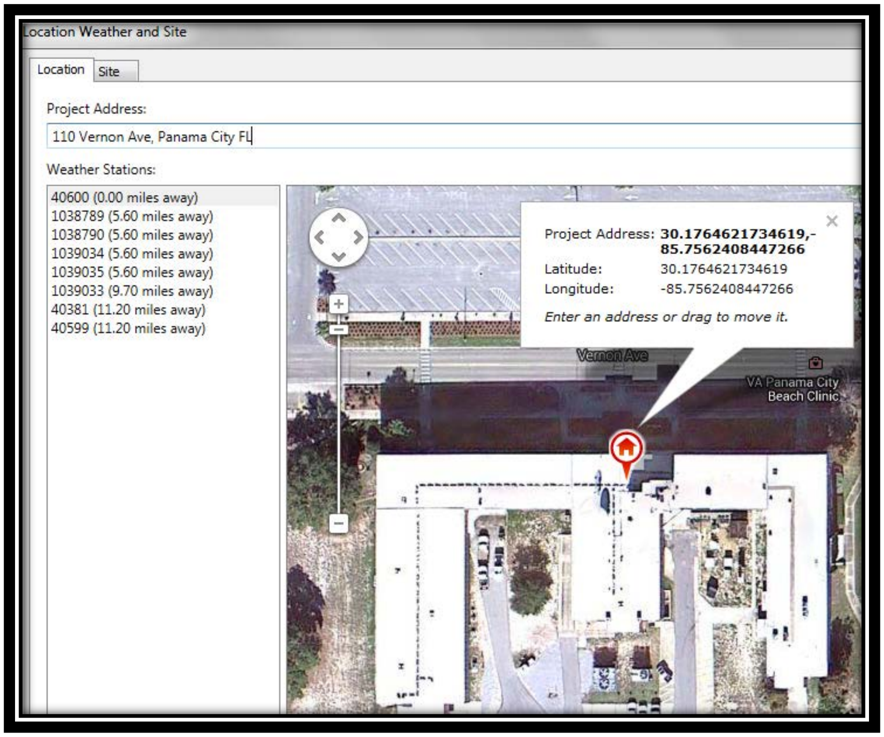


Figure 9-Bing Birdseye Image

Potential Energy Savings Analysis

Green Building Studio allows automatic analysis of Potential Energy Savings (PES) for several building features. Automatic PES analysis was performed on each building simulation run submitted. Specified building features from the model were retained and the REM process generated 50 alternative design variations with multiple options for 14 building parameters. The 50 separate parametric energy simulations were run simultaneously for each building and results were plotted against the current building conditions to give an understanding of the building's potential energy performance to for each parameter (GBSPotentialEnergySavings). The results can be visualized in table and graphical formats (Figure 11). See Appendix F for description of PES parameters and technical reference tables.

Figure 10-Energy End Use Chart Example from Green Building Studio

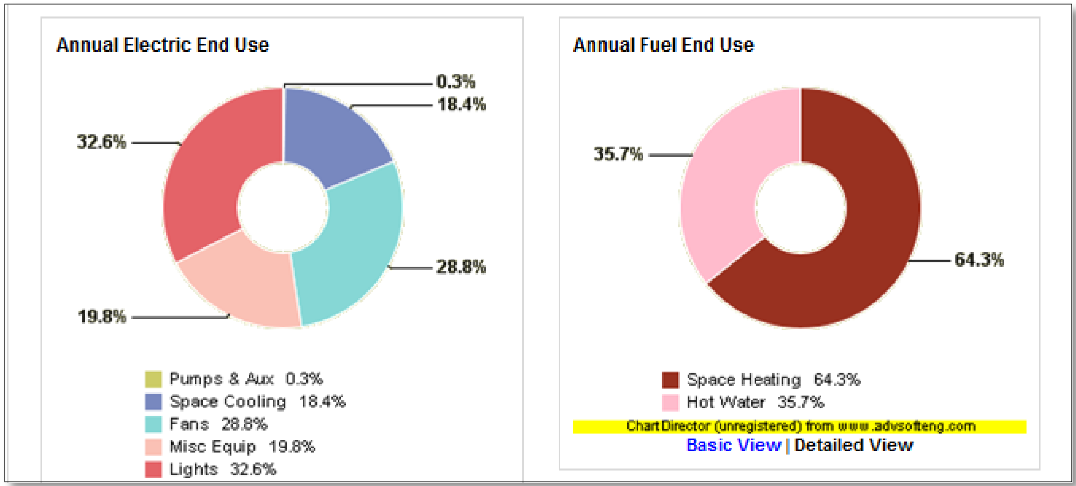
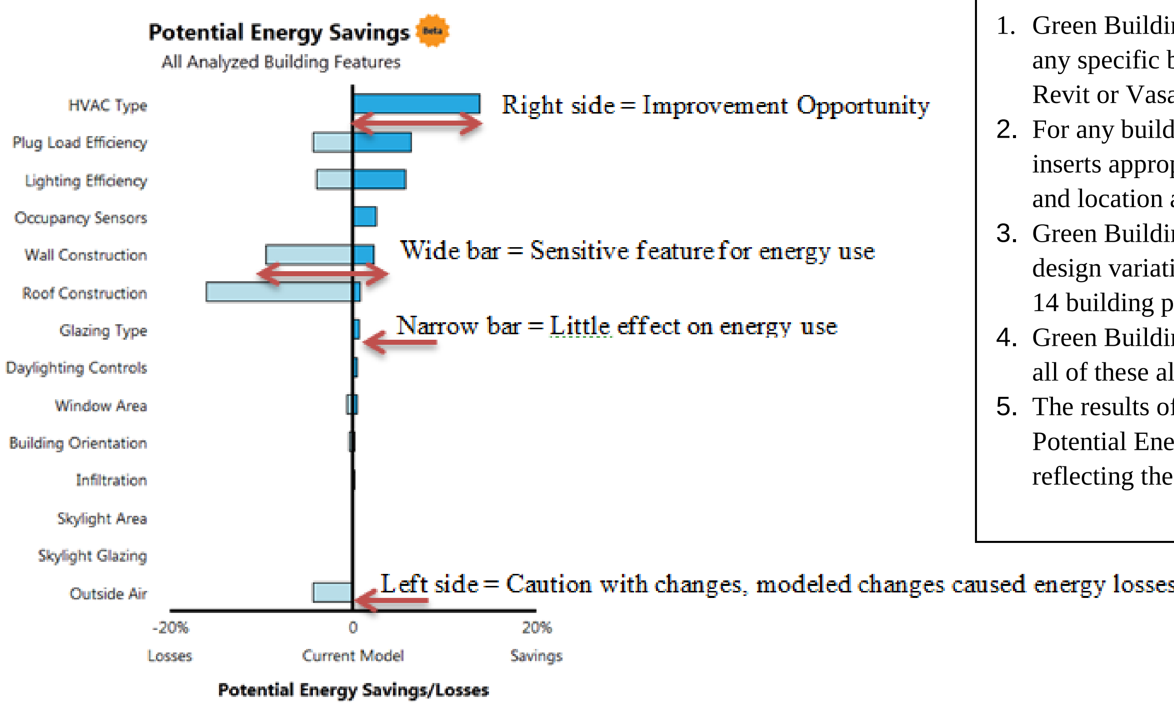


Figure 11-Potential Energy Savings Analysis



How Potential Energy Savings Analysis Works

1. Green Building Studio receives model, which contains any specific building feature design options defined in Revit or Vasari
2. For any building features that were not specified, GBS inserts appropriate default values for the building type and location and runs n energy analysis
3. Green Building Studio then generates 50 alternative design variations in the cloud with multiple options for 14 building parameters.
4. Green Building Studio then spawns 50 servers and runs all of these alternative models at the same time.
5. The results of the 51 simulations are displayed in the Potential Energy Savings chart with the center line reflecting the initial baseline run

Design Alternatives and ECMs

Results from PES analyses were used to explore Energy Conservation Measures (ECMs) for a subset of 5 DoD buildings. Researchers were able to modify base assumptions in the building energy model and run additional simulations to estimate impacts of energy conservation measures (ECMs) informed by PES analysis runs. Currently, PES analyses and design alternatives do not incorporate cost of measures, therefore researchers explored different scenarios for each building, including:

1. Basic Package - which may include LPD or EPD improvements of 10%, occupancy sensors and daylighting controls or possibly HVAC system upgrade using a similar system and infrastructure to what currently is present.

2. Advanced Package – which may include the above, and also envelope improvements such as wall construction and roof construction if indicated by the Potential Energy Savings chart.

Researchers did not explore changing window area, skylight area or building orientation considered in ECM packages due to feasibility, practicality and cost concerns. Changes to LPD and EPD were limited to 10% because these reductions did not have specific upgrade measures associated. Lighting power density can be reduced by lighting upgrades, ballast replacements, or other lighting system performance improvements. Researchers took a conservative approach however and modeled only 10% improvements to LPD when indicated as area for potential energy savings; it is quite possible that a systems approach to reducing lighting power density would yield higher energy savings. EPD measures such as improved efficiency in copiers, printers, servers, computers, monitors etc. could help reduce EPD. Additionally, training employees to set computers and monitors into standby mode can reduce EPD. Together or separately, these strategies can lead to significant energy savings, and may exceed the conservative 10% savings modeled for EPD and LPD in design alternatives for ECMs.

ECMs Energy and Cost Savings Analysis

The initial energy models and subsequent design alternative models provide energy consumption estimates for whole buildings, and also provide annual energy cost estimates. The cost function is dependent on rates for energy sources, provided by installation POCs as $/kWh and cost/therm, and incorporated into the model assumptions. Energy usage and cost estimates for baseline building models were compared to metered energy usage and extrapolated costs. Upon completion of energy conservation measure simulations, the energy savings and energy cost savings potential for the retrofit solutions were evaluated.

5.4 OPERATIONAL TESTING

The relevant mode of operation is a standard methodology including: installation solicitation, data capture, site selection, site access, capturing imagery and measurements, assembling models, generating energy reports, analyzing and comparing energy data to meter data and CBECS, then exploration of energy conservation measures (Table 4; Figure 12). The testing occurred between October 2012 – October 2013 (Figure 13).

Figure 12-Operational Phases

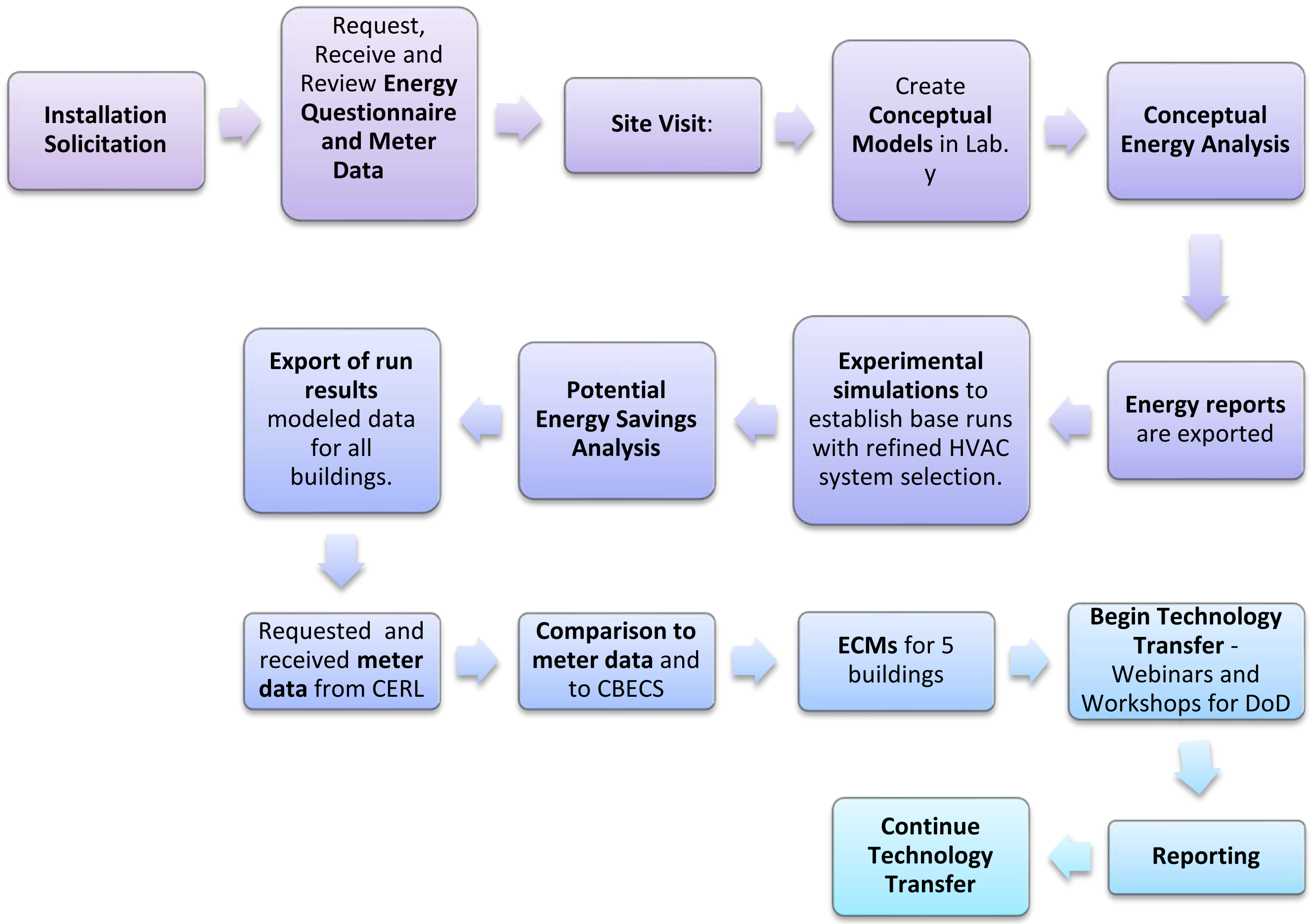
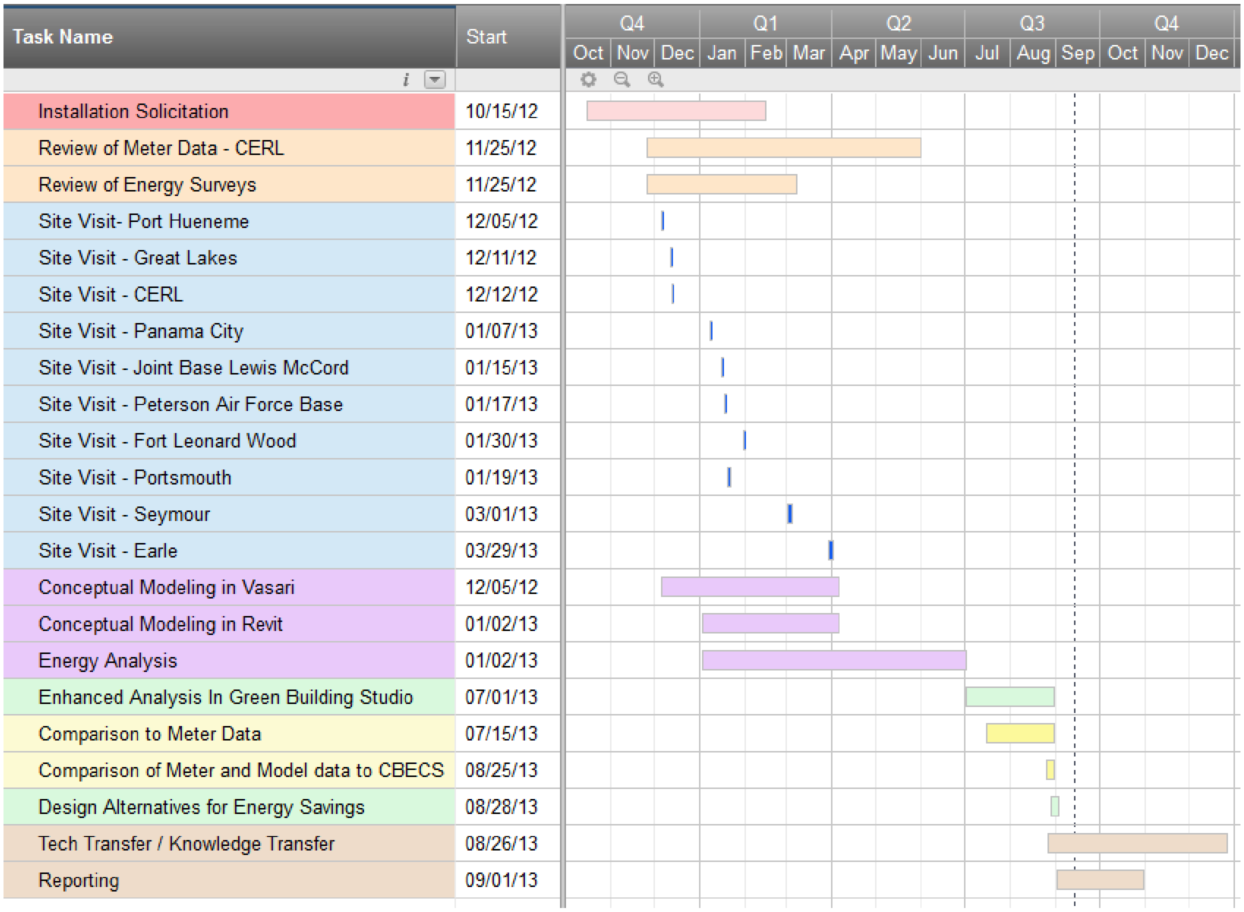


Figure 13-Dates and Duration of Operations



Task Name	Start
Installation Solicitation	10/15/12
Review of Meter Data - CERL	11/25/12
Review of Energy Surveys	11/25/12
Site Visit- Port Hueneme	12/05/12
Site Visit - Great Lakes	12/11/12
Site Visit - CERL	12/12/12
Site Visit - Panama City	01/07/13
Site Visit - Joint Base Lewis McCord	01/15/13
Site Visit - Peterson Air Force Base	01/17/13
Site Visit - Fort Leonard Wood	01/30/13
Site Visit - Portsmouth	01/19/13
Site Visit - Seymour	03/01/13
Site Visit - Earle	03/29/13
Conceptual Modeling in Vasari	12/05/12
Conceptual Modeling in Revit	01/02/13
Energy Analysis	01/02/13
Enhanced Analysis In Green Building Studio	07/01/13
Comparison to Meter Data	07/15/13
Comparison of Meter and Model data to CBECS	08/25/13
Design Alternatives for Energy Savings	08/28/13
Tech Transfer / Knowledge Transfer	08/26/13
Reporting	09/01/13

5.5 SAMPLING PROTOCOL

Table 5-Sampling Parameters and Types

Performance Objective	Parameters	Number and Type of Samples
Correlation of REM with Annual Energy Electricity Intensity & Annual Fuel Intensity	Electricity and natural gas data from model and from meters	Meter data information; minimum of 1 year data and minimum monthly intervals Model data: Electric and natural gas model data is visible in annual and monthly intervals CBECS data: CBECS annual kBtu/ ft² electric and natural gas respectively
Correlation of REM with Annual Energy Intensity	Electricity + Fuel = EUI	Meter data information; minimum of 1 year data and minimum monthly intervals for fuel and electric Model data: Fuel model data assumes natural gas; it is visible in annual and monthly intervals CBECS data: CBECS annual EUC kBtu/ ft²
Variance in Monthly Consumption (Billing History)	Billing rates	Utility bills were unavailable. CVRMSE was calculated between monthly modeled versus metered billing costs based on utility rates provided and using monthly energy use
Energy reduction through GBS modeling of Energy Conservation Measures	% energy savings in kWh and therms; cost savings in $	PES analyses within Green Building Studio were used to identify design alternatives for energy conservation measures for 5 buildings. Documentation of energy and cost savings vs. model and meter data.
Time and cost to energy model	Hours or Hours/ square foot; $/ ft²	Published data in preparation for publication was used to assess average hour and cost requirements for ASHRAE Level 2 audits
Ease of learning technology and expertise required	Person- hours of training to complete initial building energy models	Autodesk staff to optimize workflows based on experience, input requirements and constraints, conduct hands-on workshops with DoD personnel and walk them through the workflow
User Satisfaction	Satisfaction with REM workflow and processes	Installation personnel to be surveyed regarding their satisfaction
Ability to scale across DOD	Number of REM trained personnel at end of pilot study, time to complete models	Documentation of number of personnel trained.

Data quality and consistency issues are outlined in Section 8.0 and Appendix D. Inconsistencies and missing data were encountered in reviewing energy surveys and meter data. Energy survey questions were in some cases left blank, in other cases completed but with the respondent indicating uncertainty. Researchers documented missing data. If missing or questionable data was necessary for completion of the energy model, researchers made and documented assumptions related to the data.

Review and verification of the building meter data revealed numerous issues related to data quality including: lack of stated natural gas or electric data, zero readings, negative readings, make-up readings, time gaps, large usage/EUI jumps, duplicate timestamps, scaling issues (see Appendix D).

5.6 SAMPLING RESULTS

Table 6-Summary Info on Data Collected

<table>
<tr><th>Division</th><th># of Buildings Visited</th><th># of Buildings in Core Study Set</th><th>Captured Data Pre-site Visit For each Building</th><th>On Site Information For each building</th><th>Models- For each building</th><th>Reports For each building</th></tr>
<tr><td>Army</td><td>8</td><td>7</td><td rowspan="5">• Meter Data
• Energy Survey
• Location and Satellite image</td><td rowspan="5">• Photos of building exterior (often non-essential)

• Reference measurement of building footprints (non-essential)

• Clarifying questions re: energy survey</td><td rowspan="5">• Conceptual 3D models
• Green Building Studio XML</td><td rowspan="5">Green Build Studio Dashboard Charts

Green Building Studio Data Tables

Monthly and Annual tables and graphs of modeled parameters, such as kWh, therms, and EUI plotted in relation to results from building meters. This gives valuable information on performance of the energy model in comparison to the meter data, seasonal variations, and trends in building types.</td></tr>
<tr><td>Navy</td><td>14</td><td>5</td></tr>
<tr><td>Air Force</td><td>9</td><td>9</td></tr>
<tr><td>Joint</td><td>4</td><td>2</td></tr>
<tr><td>Total</td><td>35</td><td>23

NOTE: 12 buildings removed due to meter data issues or use of district systems</td></tr>
</table>

Figure 14-Example Report Content from REM Process

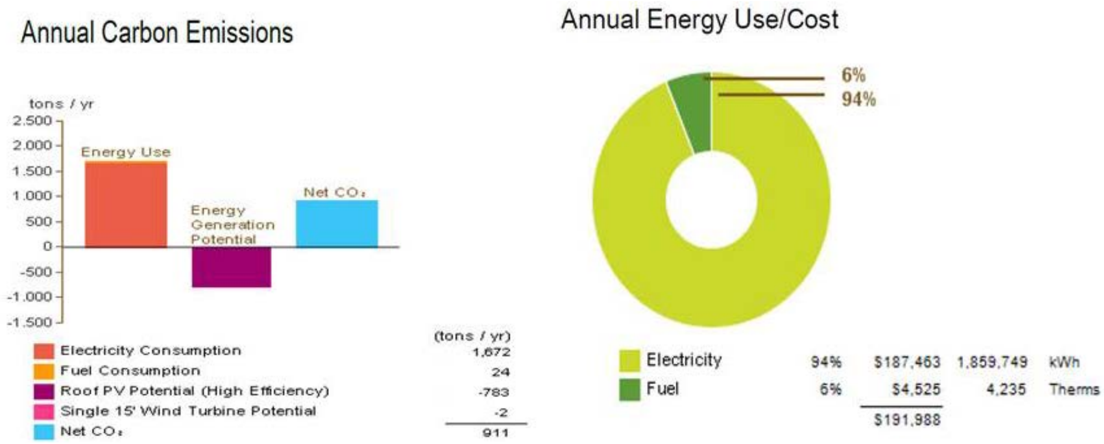


Figure 15-ECM Dashboard Listing

	Name	Energy Use Intensity (kBtu/ft²/year)	Total Annual Cost[1] Electric	Fuel	Energy	Total Annual Energy[1] Electric (kWh)	Fuel (Therm)	Carbon Emissions (tons)	Compare	Potential Energy Savings (Beta)
Project Default Utility Rates										Weather Data: GBS_04R20_178101
	Project Default Utility	--	--	--	--	--	--	--		
	Base Run									
☐	FLW_470_V_Office_:	63.0	$140,779	$9,382	$150,161	1,564,214	10,601	1,468.3	▦	▦
	⊟ Alternate Run(s) of FL									
☐	FLW 470 Advanced P	45.1	$103,842	$5,680	$109,522	1,153,805	6,418	1,001.5	▦	
☐	Basic_NO HVAC	56.8	$120,161	$10,731	$130,892	1,335,124	12,126	1,230.1	▦	
☐	FLW 470 Basic Pack:	51.6	$108,113	$10,065	$118,178	1,201,255	11,372	1,081.4	▦	

Figure 16-Annual End Use Chart

Figure 17-REM Analysis Charts

				Total Annual Cost[1]			Total Annual Energy[1]		
Floor Area (ft²)	Energy Use Intensity (kBtu/ft²/year)	Electric Cost (/kWh)	Fuel Cost (/Therm)	Electric	Fuel	Energy	Electric (kWh)	Fuel (Therm)	Carbon Emissions (tons)
4,834	69.0	$0.06	$0.66	$3,737	$799	$4,536	62,286	1,210	63.0

Energy and Carbon Results	US EPA Energy Star	Water Usage	Photovoltaic Analysis	LEED Daylight	Design Alternatives

1 Base Run

Energy, Carbon and Cost Summary

Annual Energy Cost	$4,536
Lifecycle Cost	$61,776
Annual CO_2 Emissions	
Electric	56.0 tons
Onsite Fuel	7.0 tons
Large SUV Equivalent	5.7 SUVs / Year
Annual Energy	
Energy Use Intensity (EUI)	69 kBtu / ft² / year
Electric	62,286 kWh
Fuel	1,210 Therms
Annual Peak Demand	19.7 kW
Lifecycle Energy	
Electric	1,868,595 kW
Fuel	36,296 Therms

Carbon Footprint

Base Run Carbon Neutral Potential

Annual CO_2 Emissions	tons
1 Base Run	63.0
Onsite Renewable Potential	-94.6
Natural Ventilation Potential	-11.7
Onsite Biofuel Use	-7.0
Net CO_2 Emissions	-50.3

Net Large SUV Equivalent: -4.6 SUVs / Year

Assumptions

Electric Power Plant Sources in Your Region

Fossil	83 %
Nuclear	15 %
Hydroelectric	0 %
Renewable	2 %
Other	N/A

Assumptions

REM Analysis Charts (continued)

LEED Daylight (more details)

Percentage of building area with glazing factor over 2%: **64.3% - No LEED Credit**

LEED Water Efficiency (more details)

	Gal / yr	$ / yr
Indoor:	60,122	$366
Outdoor:	26,100	$68
Total	86,222	$433

Natural Ventilation Potential

Total Hours Mechanical Cooling Required:	3,777 Hours
Possible Natural Ventilation Hours:	2,749 Hours
Possible Annual Electric Energy Savings:	10,871 kWh
Possible Annual Electric Cost Savings:	$652
Net Hours Mechanical Cooling Required:	1,028 Hours

Assumptions (i)

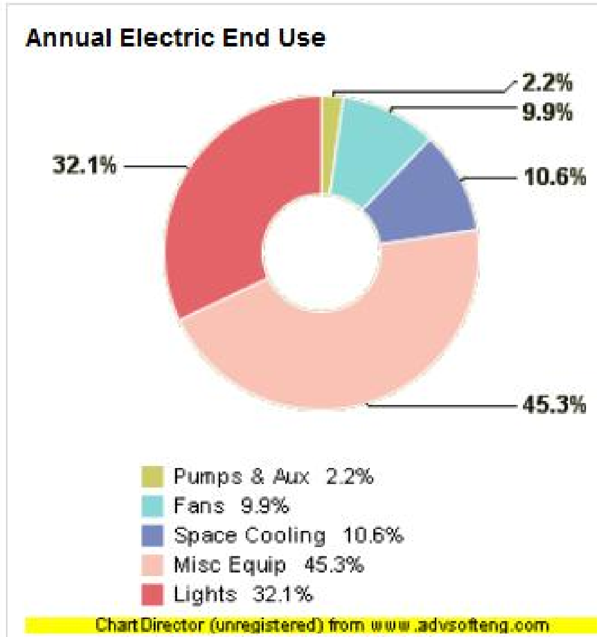
Photovoltaic Potential (more details)

Annual Energy Savings:	84,976 kWh
Total Installed Panel Cost:	$299,684
Nominal Rated Power:	60 kW
Total Panel Area:	4,673 ft²
Maximum Payback Period:	39 years @ $0.06 / kWh

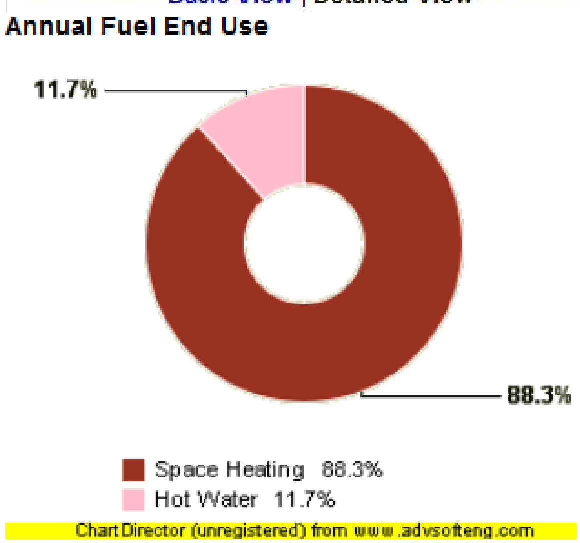
Wind Energy Potential

Annual Electric Generation:	2,785 kWh

Assumptions (i)



Basic View | Detailed View



Basic View | Detailed View

6.0 PERFORMANCE ASSESSMENT

Data collected during the demonstration provides information necessary to assess the effectiveness of Rapid Energy Modeling relative to the performance objectives defined in Table 1. The following discussion provides summary of the analysis in support of the performance objectives.

6.1 OVERALL CORRELATION OF MODELED RESULTS TO METER DATA

These measures quantified the effectiveness of Rapid Energy Modeling to estimate natural gas, electric and overall energy usage of individual buildings within 10% error compared to meter data provided by the installation. Prior case studies that guided establishment of the 10% error targeted traditional commercial office buildings with standard operating hours and usage. DoD buildings in the sample vary widely in their occupancy and usage and a re-established success criteria of $\leq$20% error is a better metric to evaluate forecast accuracy. Mean Bias Error (MBE) and mean absolute percentage error (MAPE) are used to assess forecast performance. Lewis's interpretation of MAPE results (1982) is criteria used to judge the accuracy of the forecast and is summarized in Table 2.

Energy use is a frequently tracked metric for many buildings, yet there are many buildings that do not have meters installed, meters are not functioning and or data is not usable (see list of meter-related issues in Section 8.0). Rapid energy modeling predicts how buildings should be performing (or where buildings are potentially used in non-standard ways), based on their use profile, unique geometry, generalized use schedules and location and construction characteristics for buildings of their type and region. Where model input parameters are not known, many sources are used to define defaults based on CBECS, design tables within ASHRAE/IESNA Standard 90.1-2004, scientific research papers and modeling best practices. This provides a rational baseline of information from which to make asset management decisions.

The models predicted energy usage using Green Building Studio, driven by the DOE 2.2 engine. Meter data received from the installations was reviewed by a third party (ERDC-CERL) prior to comparison with modeled estimates. In some cases, despite verification, subsequent issues were encountered with the meter data that required removal from the study or aspects of the analysis. Of a population of 35 buildings, a total of 23 buildings were included in core analyses. 12 buildings were excluded from core analyses due to:

- Questionable meter data and scaling issues - 3 Earle buildings, 1 JBLM building
- Building occupancy concerns (FLW 1 building; JBLM 1 building)
- Absence of natural gas data (Port Hueneme, 3 buildings; Great Lakes 3 buildings)

The removed buildings were analyzed separately to the extent possible and are summarized in Appendix C.

Electric Results

Overall, the mean absolute percentage error for electric results was 18.12%, representing average accuracy of 81.88% (n=23) (Table 8; Figure 22). Although MAPE of 18.12% is outside of the success criteria described in the performance objectives, stated as +/-10%, it is still considered a "good" forecast according to criteria established by Lewis (1982). Correlations in energy use curves were evident in most buildings.

Natural Gas Results
Natural gas results for the 23 analyzed buildings had a MAPE of 41.80%, or an absolute average accuracy of 58.20% (Table 7). This is outside of the project's stated success criteria of +/- 10% error, but is considered to be within the criteria of a "reasonable" forecast Lewis (1982), as it is within the range of 21-50%. In general, the models appear to be less accurate in predicting actual natural gas usage than electric usage in DoD buildings. This may be due to errors in modeling results, but the natural gas model results align closer with CBECS natural gas values than the metered natural gas values and may point to other sources of error. Natural gas is much more sensitive to HVAC settings and climate than electricity because natural gas in the energy model is only for:

1. Hot water (very small amount but very sensitive to user operation)
2. Heating (very sensitive to climate and building operation) ; feedback from personnel indicates that HVAC systems are often operated excessively
3. Reheat (very sensitive to HVAC settings and often set up very poorly)
4. Infiltration
5. Various very large process loads like a pool, cafeteria, or other unique things that are not typically part of a rapid energy model

These issues can be checked fairly easily in buildings and are good candidates for re-commissioning. Overall, metered values are much higher than modeled values, with the exception of a LEED building, and two dorm buildings with questionable occupancy levels.

Energy Use Intensity Results
EUI results had a MAPE of 22.44% (N=23), representing 77.56% absolute average accuracy in EUI predictions (SD=13.48%). This MAPE for the pooled set of buildings is within the stated performance objective criteria of =/- 25% error, and is considered "reasonable" according to established criteria, as it falls between 21%-50% MAPE (Table 7). Absolute error for individual buildings is summarized in Figure 18. The highest energy use, represented by EUI (kBtu/ ft^2), was found in a cafeteria, dormitories and a gymnasium (Figure 19 and 20).

In most cases, there was closer alignment of simulation data to CBECS result, and researchers attribute the deviation between the model and meter data to buildings that are performing worse than should be expected based on their attributes.

To further explore the results, analyses were clustered by building use type and plotted against benchmarking results from the CBECS 2003 survey. Examination of this range of buildings improved the findings of the demonstration by allowing visibility of trends within use categories. The various building types included:

- 13 offices
- 5 barracks
- 5 specialty use buildings (fire station, gym, school, auto facility, cafeteria)

Table 7-Summary Data for All Analyzed Buildings (n=23) ***(See also Appendix B)***

Statistics	Electric	Natural Gas	EUI
Average Accuracy	81.88%	58.20%	77.56%
Mean Absolute Percentage Error	18.12%	41.80%	22.44%

Figure 18-Comparison of Absolute Error Percentages Across Buildings

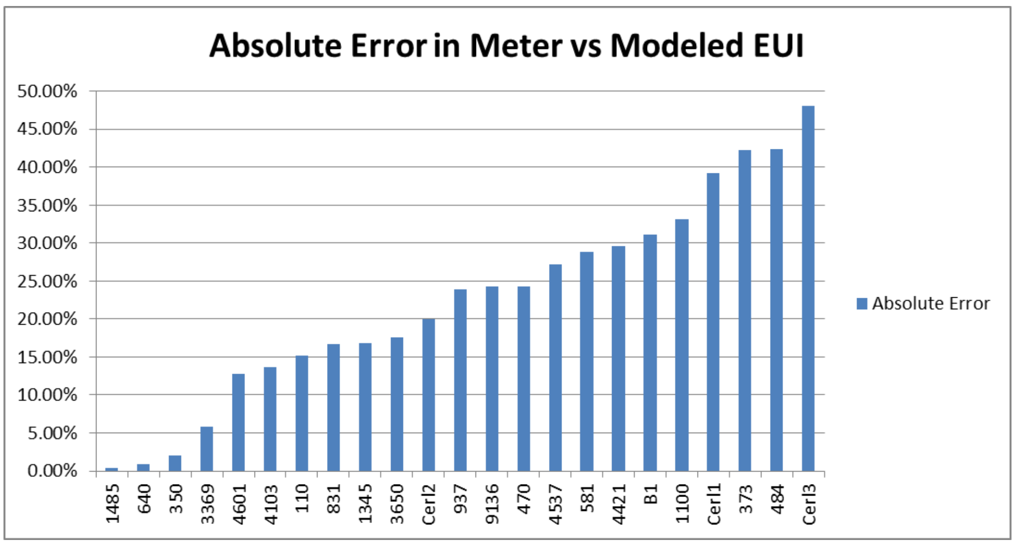


Figure 19-Comparison of Meter and Model Data in Relative kBtu/ ft²

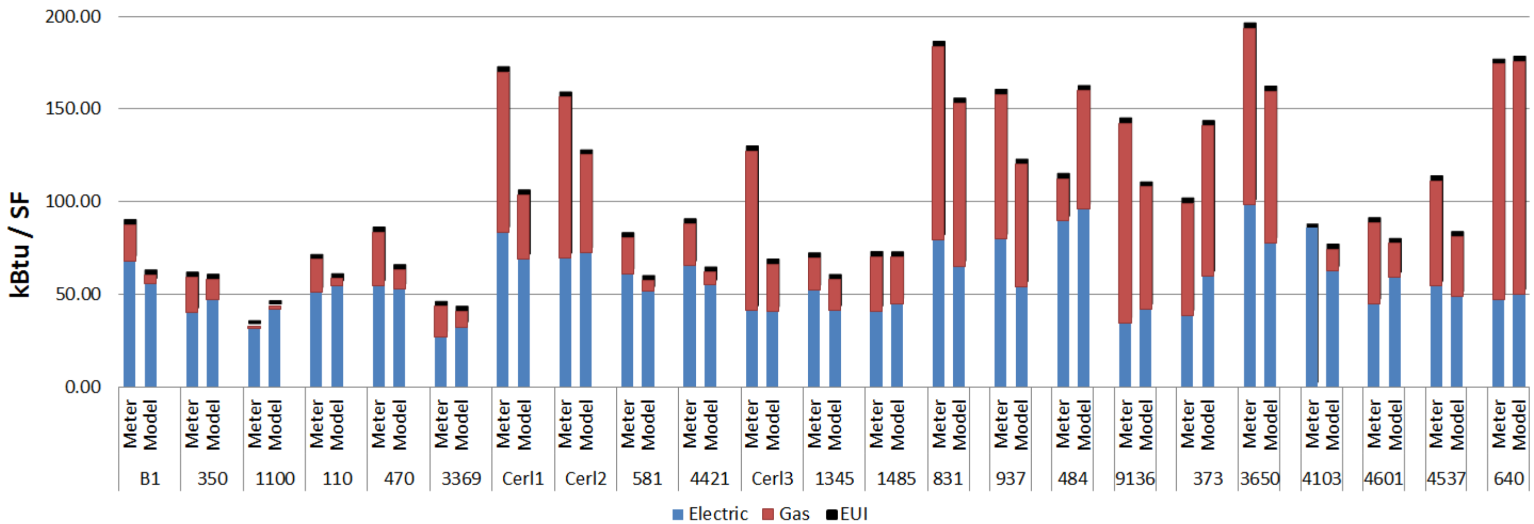
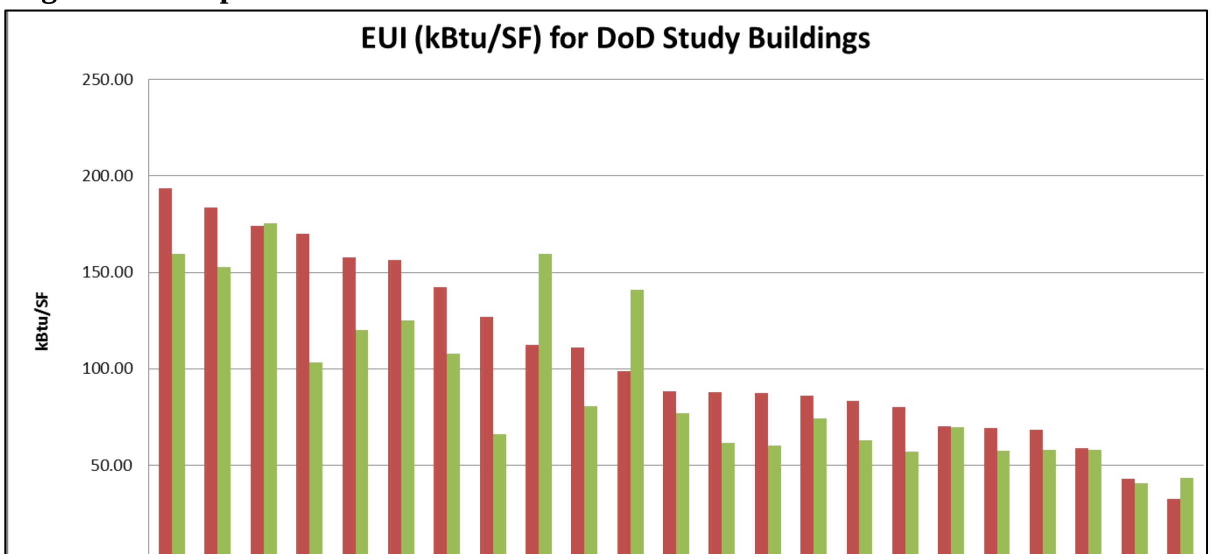


Figure 20-Comparison of Meter and Model Data in Relative kBtu/ ft²

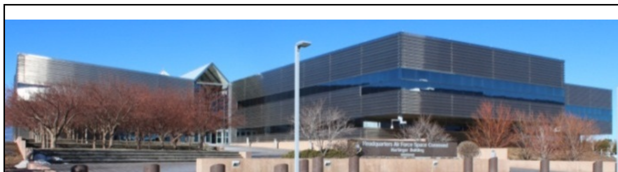
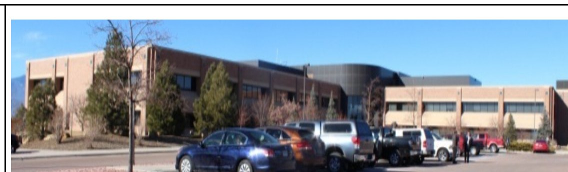
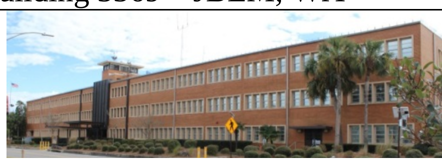
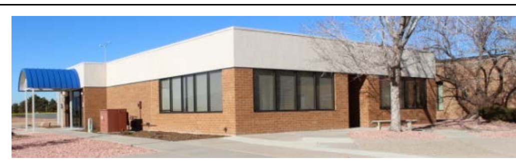
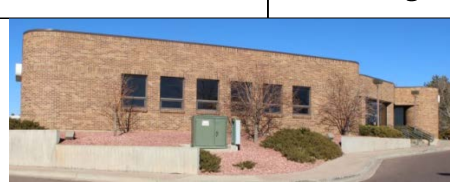


	3650	831	640	Cerl1	937	Cerl2	9136	Cerl3	484	4537	373	4601	4421	B1	4103	470	581	1485	1345	110	350	3369	1100
EUI - Meter	193.4	183.5	173.9	169.8	157.6	156.2	142.1	127.1	112.2	111.0	98.98	88.37	87.70	87.33	85.85	83.28	80.23	70.12	69.34	68.52	58.95	43.08	32.68
EUI Model	159.4	152.9	175.5	103.2	119.9	124.9	107.6	66.04	159.7	80.84	140.7	77.09	61.71	60.15	74.14	63.00	57.12	69.85	57.70	58.13	57.77	40.55	43.51

6.1.1 Offices Subset

In total, 13 offices across seven Army, Navy and Air Force locations participated in the core analysis in the study. The offices ranged in size from 4,800 gross square feet to 281,732 gross square feet (Table 8).

Table 8-Office Buildings - Photos

 Building 1 – Peterson AFB, CO	 Building 350 – Peterson AFB, CO
 Building 3369 – JBLM, WA	 Building 1100 – Port Hueneme, CA
 Building 110 – Panama City, FL	 Building 470 – Fort Leonard Wood, MO
 Building 4421 – Seymour AFB, NC	 Building 581 – Panama City, FL
 CERL 1 – ERDC-CERL, Champaign, IL	 CERL 2 – ERDC-CERL, Champaign, IL
 CERL 3 – ERDC-CERL, Champaign, IL	 Building 1485, Peterson AFB, CO
 Building 1345, Peterson AFB, CO	

The offices overall averaged 85.70% in accuracy when comparing modeled estimates for electric data to electric meter data, representing average MAPE of 14.30%, considered a good forecast based on criteria proposed by Lewis (1982). While electric modeling results for offices aligned closely with actual metered usage, natural gas models for offices were on average only 49.48% accurate, with a MAPE of 50.52%, which is considered a reasonable forecast, but is on the cusp of being considered inaccurate (MAPE $\geq$51%).

Energy surveys were revisited to investigate buildings where modeled estimates were more than 20% different than meter data. For the office electric data, only Naval building 1100 in Port Hueneme (33.83% error) and Office Building 1345 at Peterson (-21.33% error) were outside of this threshold (Table 10; Figure 25). The energy model for Building 1100 estimated electricity usage at higher levels that were indicated by the building meters for this building (Figure 21 and 22). Port Hueneme was the only installation that could not identify their HVAC systems, so researchers used general descriptions and observations to attempt the appropriate HVAC selection. It is possible that that modeled heating and cooling days are not in alignment. Building 1345 is a small bank building, and the energy model underestimated energy usage. The modeled and metered electric data are well aligned in trend profiles and usage from May – September, however in October – April metered there were amplitude differences and usage was higher than predicted by the model (Figure 26). This difference could be related to seasonal weather conditions for the year.

Only three buildings were $\geq$80% accurate for natural gas estimates and those included: Port Hueneme 1100 and the two smallest buildings, 1345 and 1485 at Peterson AFB (Table 9; Figure 21). The office buildings demonstrated correlation in trend profile shape, but had significant amplitude differences, with the building consuming more natural gas than predicted by the model.

In all cases, with the exception of Building 1100, building natural gas meter and EUI data is higher than what is predicted in the models. While the possibility exists that differences could be attributed to natural gas use related calculations in the models, it should be noted that in general, building natural gas usage and EUI were also significantly higher than CBECS values. Researchers attribute the deviation between the model, meter, and CBECS results to buildings that are performing worse than should be expected based on their location and attributes.

Figure 21-Percent Deviation - Model vs. Meter Data (Offices)

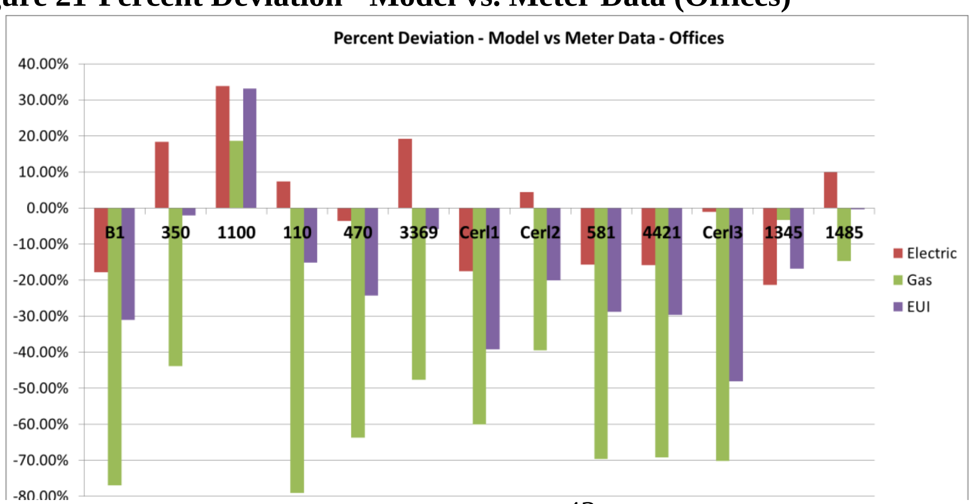
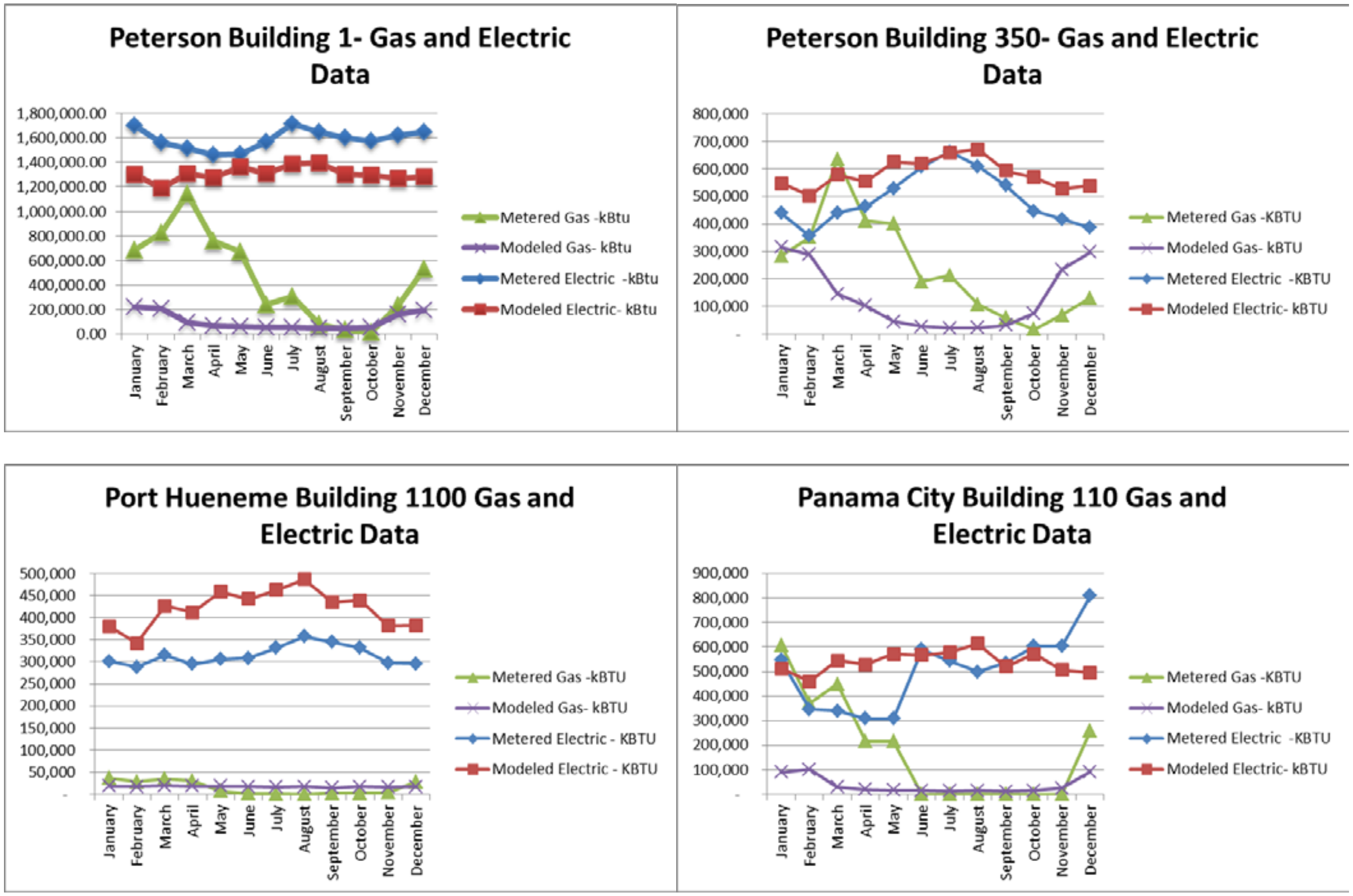
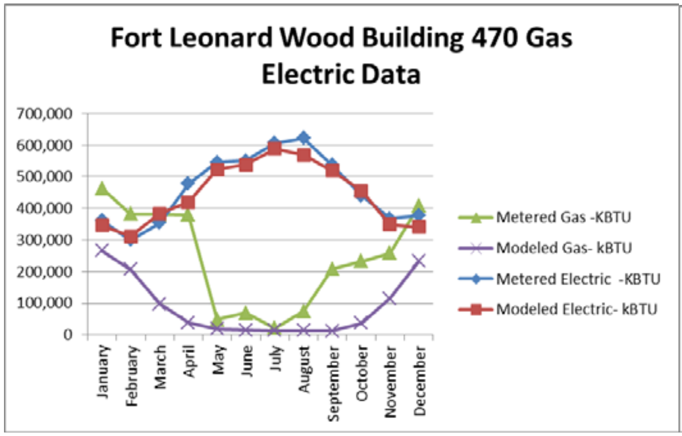


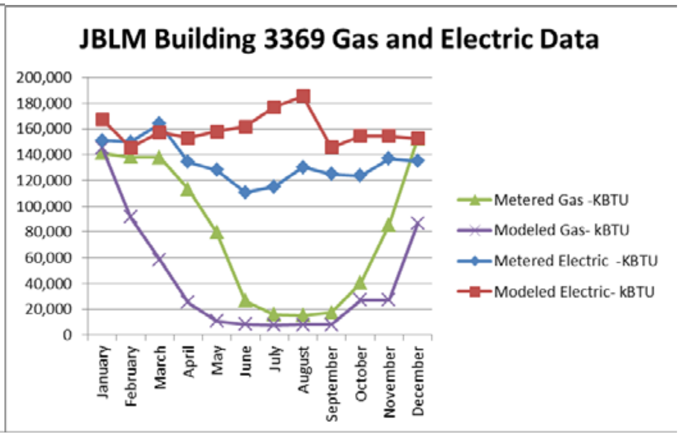
Table 9-Summary Data for Offices

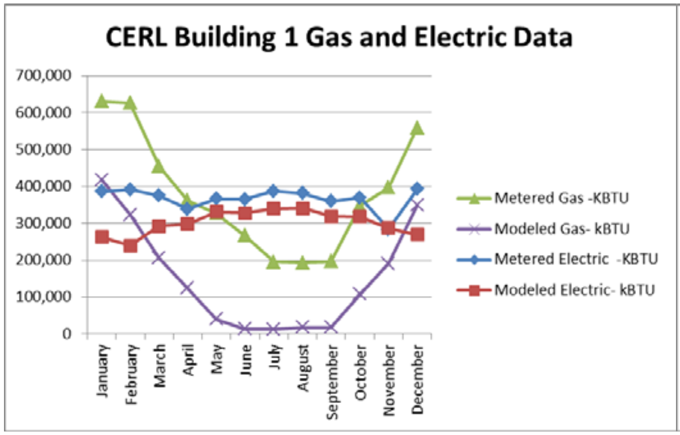
Building Number	Building Type - Modeled	Division	Gross Floor Area-Modeled Conditioned Space	State	kWh From Meter	kWh from Model (GBS)	Mean Bias Error-Model Vs Meter - Electric	Accuracy Model Vs Meter - Absolute (Elec)	MMBTU From Meter	MMBTU From Model (GBS)	Mean Bias Error- Model Vs Meter - Gas	Accuracy Model Vs Meter Absolute (Gas)	Total Metered EUI (kBtu/SF)	Total Modeled EUI (kBtu/SF)	Mean Bias Error- Modeled Vs Metered - EUI (kBtu/SF)	Accuracy Model Vs Meter - Absolute (EUI)
B1	Office	Air Force	281,732	CO	5,590,418	4,593,182	-17.84%	82.16%	5524	1270.54	-77.00%	23.00%	87.33	60.15	-31.12%	68.88%
350	Office	Air Force	148,801	CO	1,728,137	2,046,233	18.41%	81.59%	2873.363	1611.969	-43.90%	56.10%	58.95	57.77	-2.00%	98.00%
1100	Office	Navy	120,925	CA	1,105,292	1,479,161	33.83%	66.17%	179.1	212.5311	18.67%	81.33%	32.68	43.51	33.14%	66.86%
110	Office	Navy	119,050	FL	1,768,200	1,897,648	7.32%	92.68%	2122.8	443.871	-79.09%	20.91%	68.52	58.13	-15.17%	84.83%
470	Office	Army	101,565	MO	1,621,858	1,564,214	-3.55%	96.45%	2922.467	1060.139	-63.72%	36.28%	83.28	63.00	-24.35%	75.65%
3369	Office	Joint Base	59,578	WA	469,930	560,350	19.24%	80.76%	962.9	503.6395	-47.70%	52.30%	43.08	40.55	-5.87%	94.13%
Cerl1	Office	Army	52,739	IL	1,288,807	1,062,475	-17.56%	82.44%	4560.38	1820.617	-60.08%	39.92%	169.88	103.28	-39.20%	60.80%
Cerl2	Office	Army	48,301	IL	979,952	1,022,858	4.38%	95.62%	4200.35	2543.372	-39.45%	60.55%	156.21	124.93	-20.02%	79.98%
581	Office	Navy	40,287	FL	716,700	604,483	-15.66%	84.34%	786.1	238.2419	-69.69%	30.31%	80.23	57.12	-28.80%	71.20%
4421	Office	Air Force	37,088	NC	706,325	594,687	-15.81%	84.19%	842	259.2037	-69.22%	30.78%	87.70	61.71	-29.63%	70.37%
Cerl3	Office	Army	23,639	IL	282,577	279,563	-1.07%	98.93%	2040.17	606.9196	-70.25%	29.75%	127.10	66.04	-48.04%	51.96%
1345	Office - Bank	Air Force	7,772	CO	118,197	92,989	-21.33%	78.67%	135.53	131.0553	-3.30%	96.70%	69.34	57.70	-16.79%	83.21%
1485	Office - Bank	Air Force	4,834	CO	57,680	63,413	9.94%	90.06%	142.1	121.2382	-14.68%	85.32%	70.12	69.85	-0.38%	99.62%
Summary Data for Offices							Average Accuracy	85.70%			Average Accuracy	49.48%			Average Accuracy	77.34%
							Mean Absolute Percentage Error (MAPE)	14.30%			MAPE	50.52%			MAPE	22.66%
							STDEV	8.93%			STDEV	25.15%			STDEV	14.41%
							CoV	10.41			CoV	50.84			CoV	18.63
							MFE	2.01			MFE	18.81			MFE	21
							MAD	7.21			MAD	18.85			MAD	22
							MSE	70.28			MSE	684.38			MSE	913.06

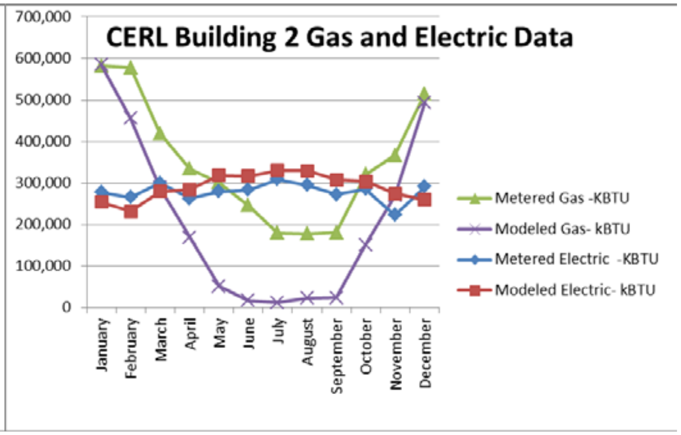
Figure 22-Monthly Natural Gas and Electric Charts - Offices

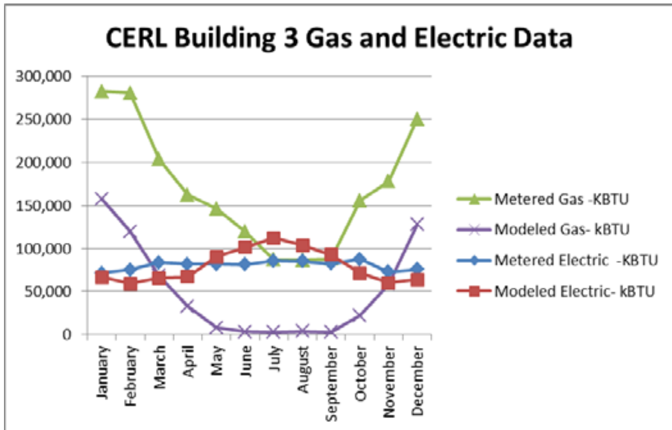


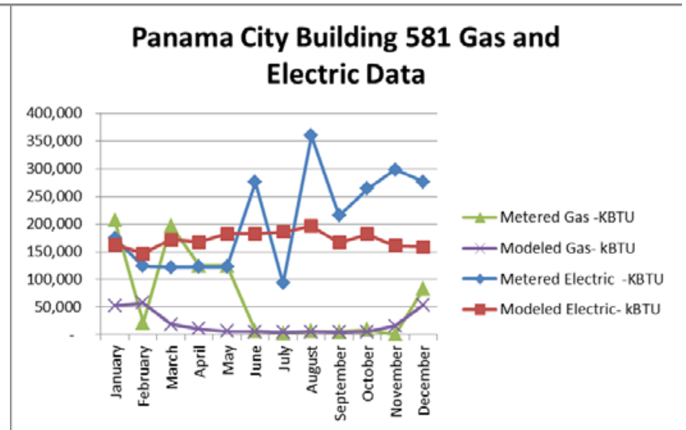

Fort Leonard Wood Building 470 Gas Electric Data
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
January
February
March
April
May
June
July
August
September
October
November
December
Metered Gas -KBTU
Modeled Gas- kBTU
Metered Electric -KBTU
Modeled Electric- kBTU

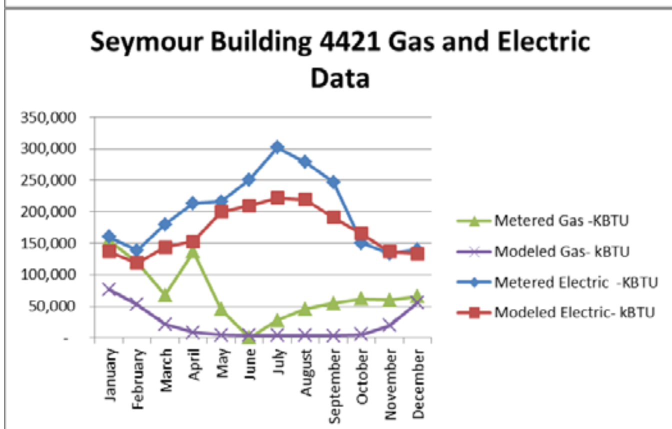

JBLM Building 3369 Gas and Electric Data
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
January
February
March
April
May
June
July
August
September
October
November
December
Metered Gas -KBTU
Modeled Gas- kBTU
Metered Electric -KBTU
Modeled Electric- kBTU

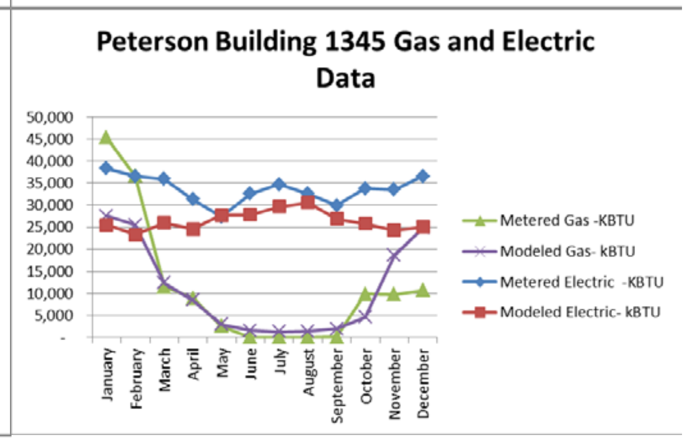

CERL Building 1 Gas and Electric Data
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
January
February
March
April
May
June
July
August
September
October
November
December
Metered Gas -KBTU
Modeled Gas- kBTU
Metered Electric -KBTU
Modeled Electric- kBTU

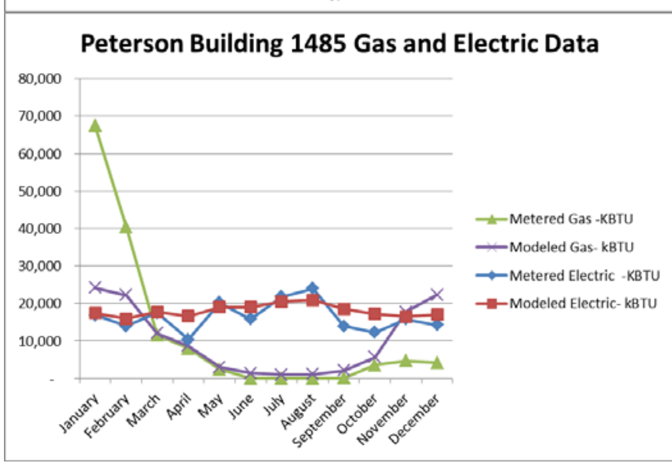

CERL Building 2 Gas and Electric Data
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
January
February
March
April
May
June
July
August
September
October
November
December
Metered Gas -KBTU
Modeled Gas- kBTU
Metered Electric -KBTU
Modeled Electric- kBTU


CERL Building 3 Gas and Electric Data
300,000
250,000
200,000
150,000
100,000
50,000
0
January February March April May June July August September October November December
Metered Gas -KBTU
Modeled Gas- kBTU
Metered Electric -KBTU
Modeled Electric- kBTU


Panama City Building 581 Gas and Electric Data
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
-
January February March April May June July August September October November December
Metered Gas -KBTU
Modeled Gas- kBTU
Metered Electric -KBTU
Modeled Electric- kBTU


Seymour Building 4421 Gas and Electric Data
350,000
300,000
250,000
200,000
150,000
100,000
50,000
-
January February March April May June July August September October November December
Metered Gas -KBTU
Modeled Gas- kBTU
Metered Electric -KBTU
Modeled Electric- kBTU


Peterson Building 1345 Gas and Electric Data
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
-
January February March April May June July August September October November December
Metered Gas -KBTU
Modeled Gas- kBTU
Metered Electric -KBTU
Modeled Electric- kBTU


Peterson Building 1485 Gas and Electric Data
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
-
January February March April May June July August September October November December
Metered Gas -KBTU
Modeled Gas- kBTU
Metered Electric -KBTU
Modeled Electric- kBTU

Overall, modeled and metered electric results aligned relatively well with CBECS 2003 benchmarking results for office building (Table 10, Figure 23). MAPE for Electric meter data compared to CBECS was 30.13% (69.87% average accuracy).

Natural gas meter data deviated greatly from CBECS with MAPE of 122.44% (-22.44% accuracy), while model data was closer aligned to CBECS with MAPE = 42.05% (57.95% accuracy).

The Rapid Energy Modeling workflow seems reasonably accurate for estimating overall EUI for DoD office buildings. Overall, of 13 offices sampled the MAPE was 22.66%, or an average of 77.34% accurate. Three office buildings (350, 3369 and 1485) were within 90% accuracy and an additional three (110, CERL 2, and 1345) were within 80% accuracy. With the exception of Building 1100 in Port Hueneme, all other office buildings had EUI meter data that was higher than predicted EUI for each building.

Conclusion

Overall, the REM workflow appears to be a good method for predicting electric usage and a reasonable method for EUI predictions for DoD office buildings when looking at mean absolute percentage errors for the pooled set of office buildings.

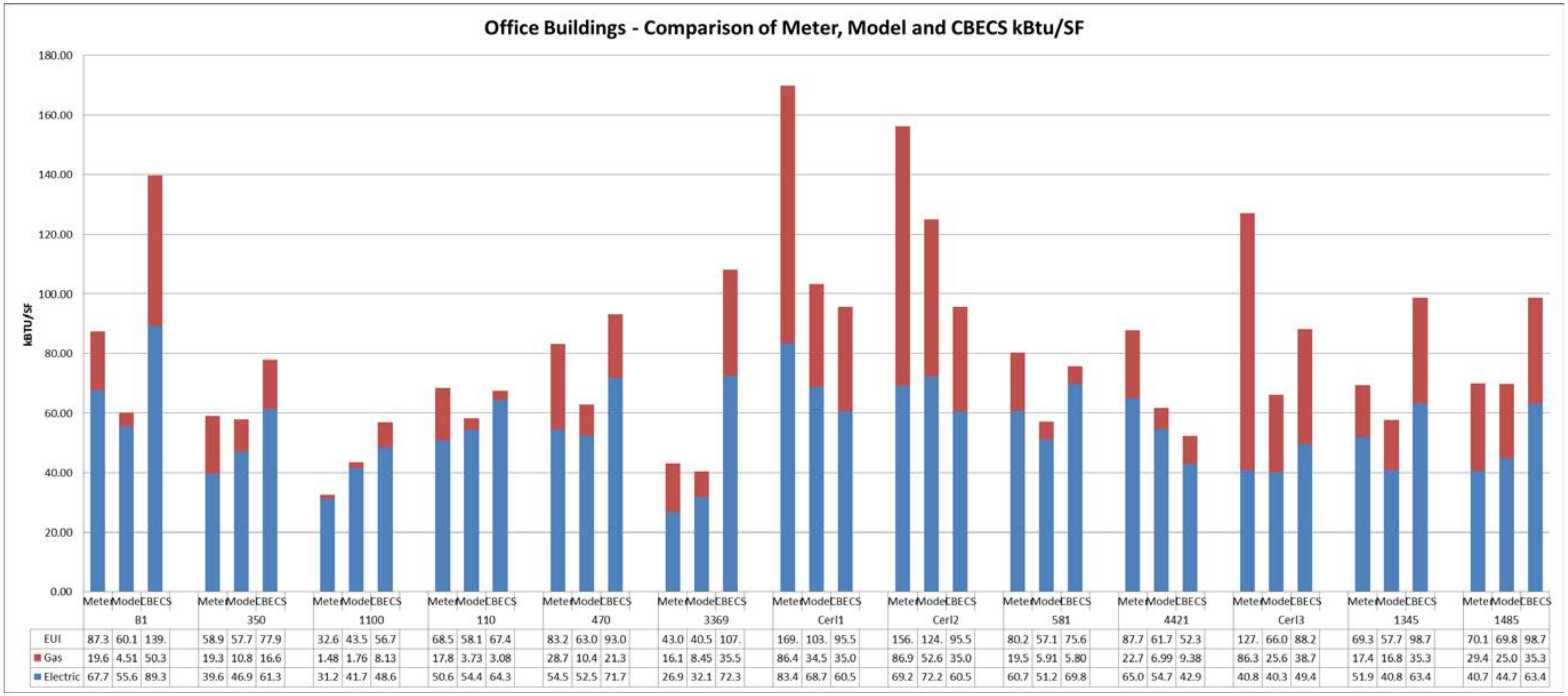
The high variability in natural gas results for individual buildings and overall mean absolute percentage error for the pooled set of office buildings needs further investigation. DoD office buildings are consuming significantly more natural gas and have higher EUI values than predicted by the models and compared to similar buildings in the CBECS database.

Energy use curves and trend profiles provide insight on seasonal variations, deviations and correlations for the buildings. Deviations are likely attributed to faulty meter readings, weather anomalies, or operational and mechanical issues at the individual building level. Next steps should include working with individual building managers to investigate operations, system configurations and settings and to attempt to elucidate understanding around spikes in usage or other anomalies in the meter data. In some cases, there may be issues with the meter data itself and there is also a possibility that the meter data was submitted for a weather year that was atypical.

Table 10-Comparison of Office Meter and Model Data to CBECS

Building Number	Metered Electric - kBTU / SF	Modeled Electric- kBTU /SF	CBECS Electric kBTU / SF	ELECTRIC Meter Difference from CBECS	ELECTRIC Model Difference from CBECS	Metered Gas -KBTU / SF	Modeled Gas- kBTU / SF	CBECS Gas KBTU/SF	GAS Meter Difference from CBECS-	GAS Model Difference from CBECS	Total Metered kBtu/SF	Total Modeled kBTU /SF	CBECS Total KBTU /SF	Meter Difference from CBECS	Model Difference from CBECS
B1	67.72	55.64	89.39	-24.24%	-37.75%	19.61	4.51	50.39	-61.09%	-91.05%	87.33	60.15	139.78	-37.52%	-56.97%
350	39.64	46.93	61.30	-35.34%	-23.44%	19.31	10.83	16.61	16.26%	-34.78%	58.95	57.77	77.91	-24.34%	-25.85%
1100	31.20	41.75	48.63	-35.85%	-14.15%	1.48	1.76	8.13	-81.78%	-78.38%	32.68	43.51	56.76	-42.43%	-23.35%
110	50.69	54.40	64.32	-21.19%	-15.42%	17.83	3.73	3.08	478.93%	21.05%	68.52	58.13	67.40	1.67%	-13.75%
470	54.50	52.56	71.75	-24.04%	-26.74%	28.77	10.44	21.26	35.35%	-50.90%	83.28	63.00	93.01	-10.47%	-32.26%
3369	26.92	32.10	72.39	-62.81%	-55.66%	16.16	8.45	35.58	-54.58%	-76.24%	43.08	40.55	107.97	-60.10%	-62.44%
Cerl1	83.41	68.76	60.52	37.81%	13.61%	86.47	34.52	35.02	146.92%	-1.42%	169.88	103.28	95.54	77.81%	8.10%
Cerl2	69.24	72.28	60.52	14.42%	19.43%	86.96	52.66	35.02	148.32%	50.36%	156.21	124.93	95.54	63.50%	30.77%
581	60.72	51.21	69.88	-13.11%	-26.72%	19.51	5.91	5.80	236.42%	1.96%	80.23	57.12	75.68	6.01%	-24.52%
4421	65.00	54.73	42.93	51.41%	27.48%	22.70	6.99	9.38	142.04%	-25.49%	87.70	61.71	52.31	67.66%	17.98%
Cerl3	40.80	40.36	49.47	-17.53%	-18.41%	86.31	25.67	38.76	122.67%	-33.76%	127.10	66.04	88.23	44.06%	-25.15%
1345	51.91	40.84	63.41	-18.14%	-35.60%	17.44	16.86	35.33	-50.64%	-52.27%	69.34	57.70	98.74	-29.77%	-41.57%
1485	40.72	44.77	63.41	-35.78%	-29.39%	29.40	25.08	35.33	-16.80%	-29.01%	70.12	69.85	98.74	-28.98%	-29.26%
			MAPE (absolute)	30.13%	26.45%		MAPE (absolute)		122.44%	42.05%		MAPE (absolute)		38.02%	30.15%
			Average Accuracy	69.87%	73.55%		Average Accuracy		-22.44%	57.95%		Average Accuracy		61.98%	69.85%

Figure 23-Comparison of Office Meter and Model Data to CBECS



6.1.2 Barracks Subset

Of 23 buildings analyzed, five were dormitories ranging in size from 25,349 GSF to 96,130 GSF. There were an additional 4 dormitories sampled that were not included in core analysis due to questionable meter data.

Table 11-Barracks Buildings - Photos

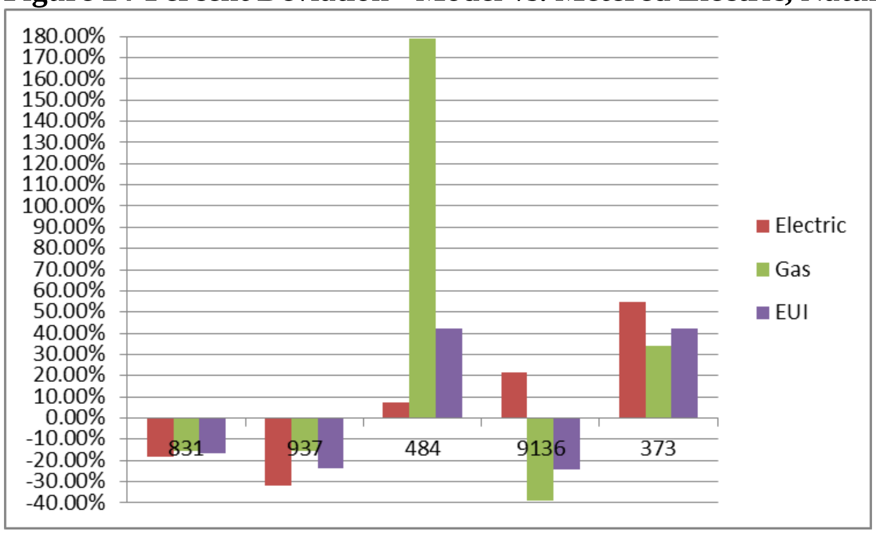
 Building 9136 – JBLM, WA	 Building 484 – Panama City, FL
 Building 831 – Fort Leonard Wood, MO	 Building 937 – Fort Leonard Wood, MO
 Building 373 – Portsmouth, ME	

Overall, dormitory electric estimates were on average 73.25% accurate when compared to meter data (MAPE = 26.75%). While this is outside of the +/- 10% success criteria established in performance objectives, it is considered a reasonable forecast according to Lewis (1982) (Table 2). Modeled natural gas predictions averaged 56.66% accuracy, including an outlier of 179% error at Panama City Building 484, where the model predicted much higher gas usage than was evident when examining meter data. With this outlier removed, natural gas accuracy averaged 73.93% with a mean absolute percentage error of 26.07% (Table 12).

Table 12-Summary Data for Barracks

Building Number	Building Type - Modeled	Division	Gross Floor Area- Modeled Conditioned Space	State	kWh From Meter	kWh from Model (GBS)	Mean Bias Error-Model Vs Meter - Electric	Accuracy Model Vs Meter - Absolute (Elec)	MMBTU From Meter	MMBTU From Model (GBS)	Mean Bias Error- Model Vs Meter - Gas	Accuracy Model Vs Meter Absolute (Gas)	Total Metered EUI (kBtu/SF)	Total Modeled EUI (kBtu/SF)	Mean Bias Error- Modeled Vs Metered - EUI (kBtu/SF)	Accuracy Model Vs Meter - Absolute (EUI)
831	Barracks	Army	40,840	MO	948,960	777,496	-18.07%	81.93%	4257.628	3593.201	-15.61%	84.39%	183.56	152.96	-16.67%	83.33%
937	Barracks	Army	55,724	MO	1,296,922	880,220	-32.13%	67.87%	4359.926	3680.78	-15.58%	84.42%	157.68	119.97	-23.92%	76.08%
484	Barracks	Navy	96,130	FL	2,513,700	2,693,241	7.14%	92.86%	2208.8	6162.982	~~179.02%~~	~~-79.02%~~	112.22	159.73	42.33%	57.67%
9136	Barracks	Joint Base	25,349	WA	255,349	310,415	21.56%	78.44%	2732.8	1669.32	-38.92%	61.08%	142.19	107.65	-24.29%	75.71%
373	Barracks	Navy	76,282	ME	858,400	1,329,284	54.86%	45.14%	4,621	6200.039	34.17%	65.83%	98.98	140.75	42.20%	57.80%
Summary Data for Barracks							Avg Accuracy	73.25%			Average w. outlier removed	73.93%			Avg Accuracy	70.12%
							MAPE	26.75%			MAPE	26.07%			MAPE	29.88%
							STDEV	18.07%			STDEV	12.25%			STDEV	11.71%
							CoV	24.67			CoV	189.12			CoV	16.69
							MFE	0.999			MFE	12.43			MFE	2.71
							MAD	14.94			MAD	22.78			MAD	38.42
							MSE	279.24			MSE	650.45			MSE	1510.58

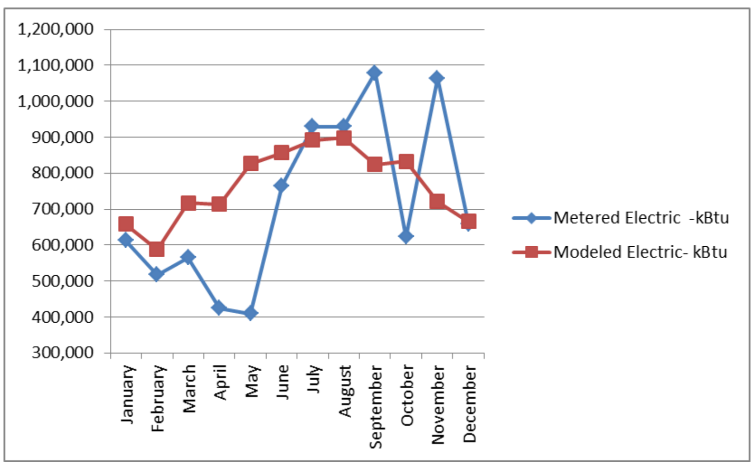
Figure 24-Percent Deviation - Model vs. Metered Electric, Natural Gas and EUI for Barracks



Dorm 484 in Panama City, Florida was the most accurate at 92.86% annually (7.14% MBE) for electric predictions; however there was a high degree of monthly variation between modeled monthly electric data and metered data. Site observations in January 2013 indicated that this large building structure does not operate at full occupancy, which is assumed by the model and when fully occupied may actually use more energy than what is indicated as peak consumption in the model (Figure 28).

Dorm 484 had the largest deviation (179%) between modeled and metered natural gas usage amongst dorms despite having the most accurate electric estimates. The data may indicate an issue with the meter data or very low occupancy in all or a large portion of the building. While onsite, researchers noted that building 484 appeared mostly vacant and functioned more as a hotel as opposed to traditional barracks and that HVAC and hot water systems may be operating at significantly reduced levels due to low occupancy. However it is important to note that natural gas is only 21% of relative consumption for this building, and electric consumption, which accounted for 79% of relative consumption, had a MBE of only 7.14%. With the exception of spikes in February and May, natural gas usage is very low, averaging only 30.88 kBtu per ft^2, when other dorms averaged between 60-100 kBtu / ft^2 for natural gas usage. Further research should attempt to identify reasoning behind the low metered natural gas usage for this building (Figure 25).

Figure 25-Dorm 484 Panama City, Florida - Electric and Natural Gas Data

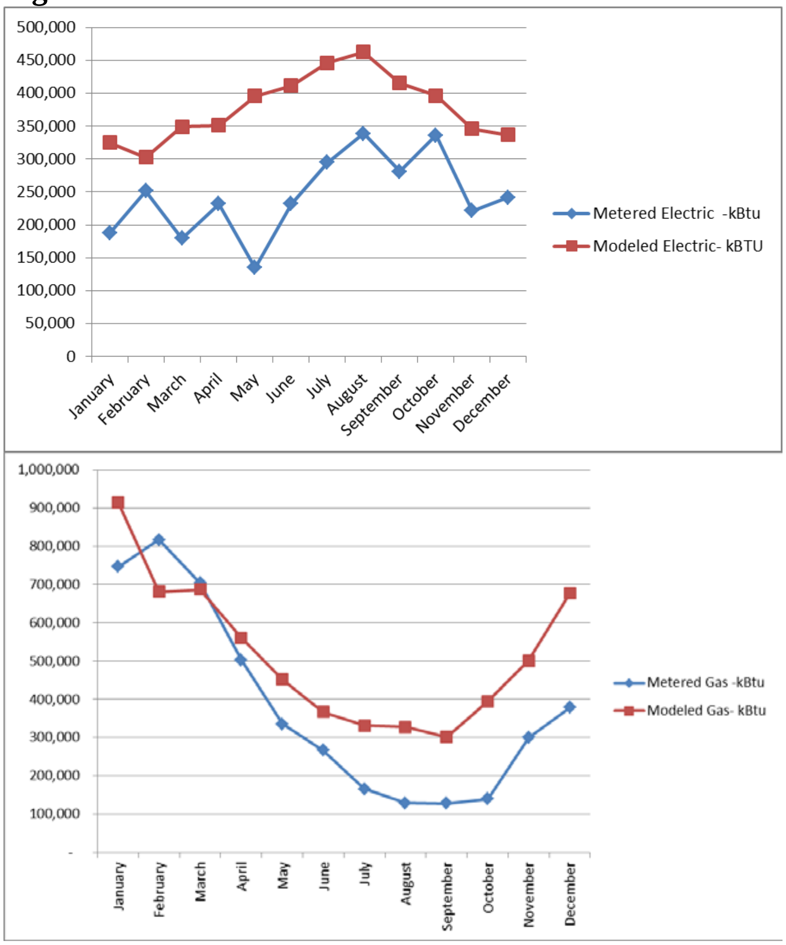


Dorm 373 at Portsmouth in Maine had the greatest deviation compared to the meter data at only 45.14% accurate. Green Building Studio estimated electric usage at a MBE of 54.86% higher than meter data readings. This difference is likely due to occupancy variations in the dorm due to troop deployments or renovations. Monthly energy results indicate periods in May, September and November where usage drops drastically (Figure 26) and this should be investigated further.

These types of occupancy variations are not something that REM is designed to account for, and show one of the primary limitations of the technique. It should be said that even if the tool could account for these variations, it is very unlikely that the input data on occupancy would be available to feed into the energy model.

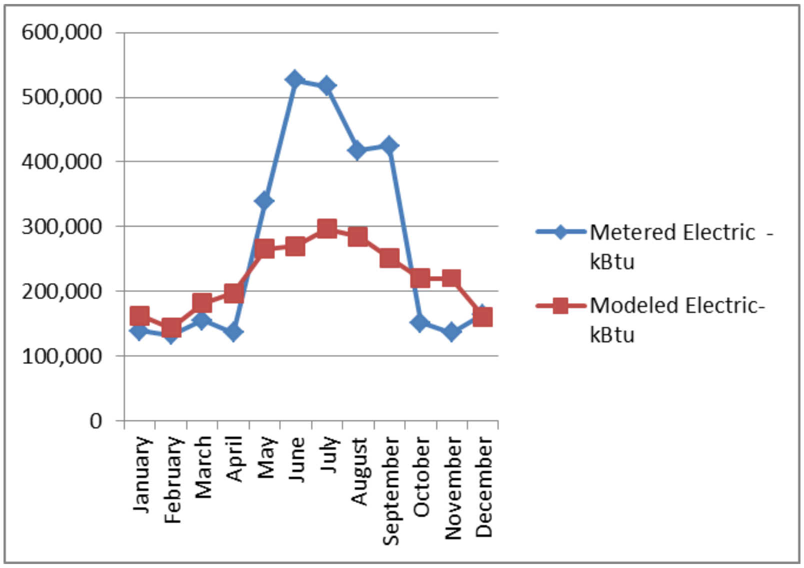
Dorm 373 was 65.83% accurate in estimate natural gas usage (MBE = 34.17%) with trend profiles that were well aligned in shape but with higher modeled natural gas usage throughout the majority of the year. These differences could be attributed to occupancy issues related to troop deployments or model assumption of 24/7 schedules for dormitories which may not apply to this building.

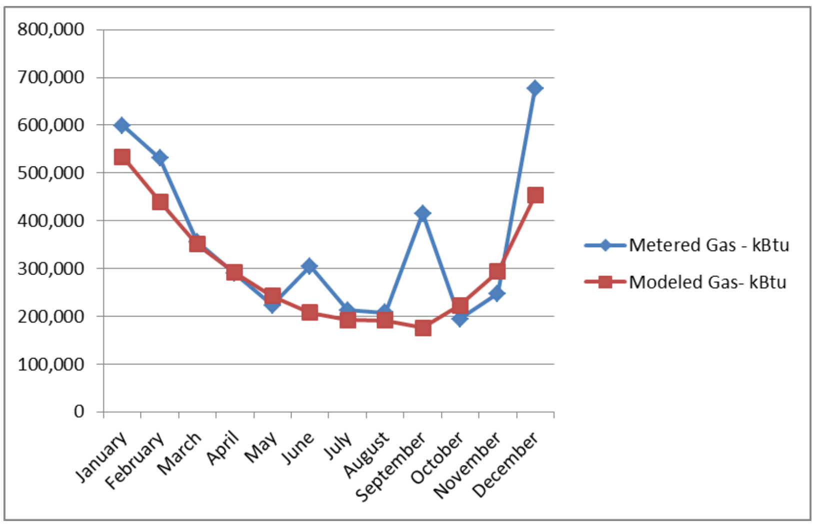
Figure 26-Dorm 373 Portsmouth Naval Base – Electric and Natural Gas Data



Building 831 at Fort Leonard Wood was 81.93% accuracy for modeled electric predictions compared to meter data (MBE = 18.07%)While Building 831 demonstrated a high degree of accuracy when comparing annual modeled estimates to meter data, monthly estimates showed high variation. It is possible that this building has electrical loads that are higher in summer months due to higher cooling use than was estimated in the model, or high plug loads due to use of personal electronics in dormitory rooms Building 831 model demonstrated 84.39% accuracy for natural gas usage estimates (MBE = 15.61%) and Building 937 at 84.42% accuracy (Table 12 above). Building 831 had an odd natural gas spike in September which could account for the difference, otherwise the overall trend between meter and modeled natural gas usage was well aligned (Figure 27).

Figure 27-Dorm 831 Fort Leonard Wood - Electrical and Natural Gas Data

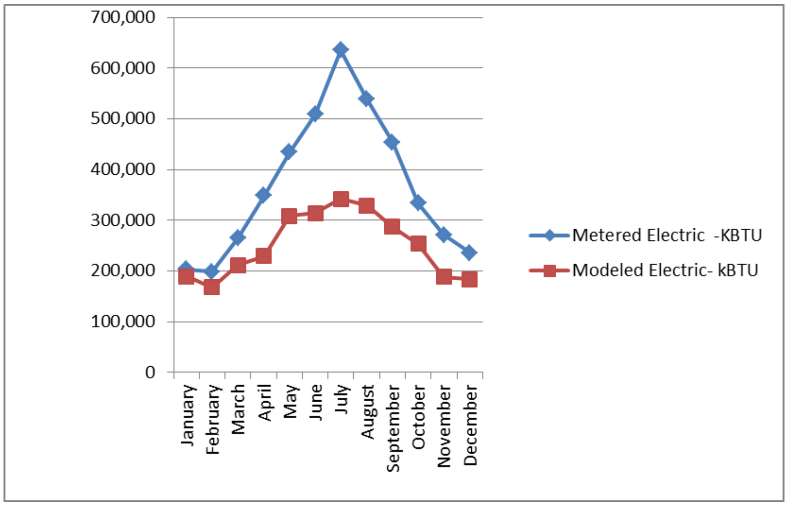


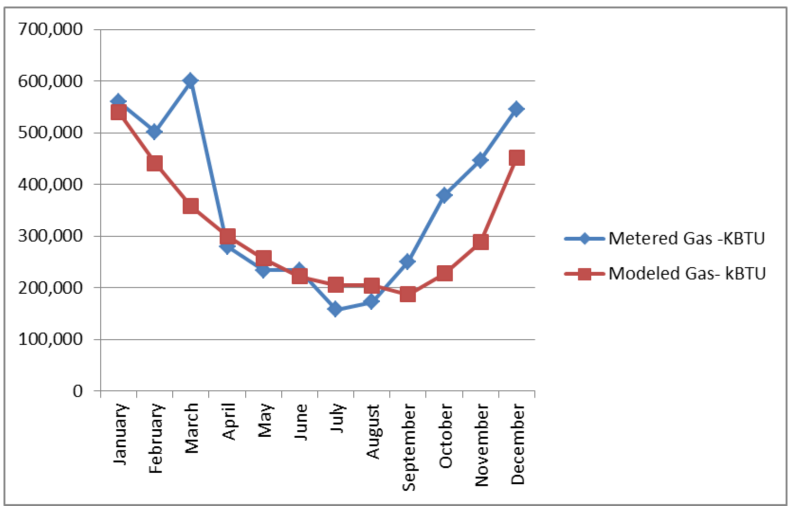


Dorm 937 at Fort Leonard Wood was 67.87% accurate for annual electrical with a MBE -21.13%. The model and meter data had similar electrical trends for the year with no extreme spikes or drops; however metered usage was significantly higher than modeled estimates from April through September (Figure 28). Natural gas model accuracy was 84.42% with a MBE of -15.58%. The natural gas trend profile for Dorm 937 was well aligned with the exception of a sharp spike in natural gas meter data in March and higher natural gas usage in October – December (Figure 28).

Typically these spike variations from normal building energy use patterns represent great opportunities to understand how to reduce energy use through better building management or retro-commissioning.

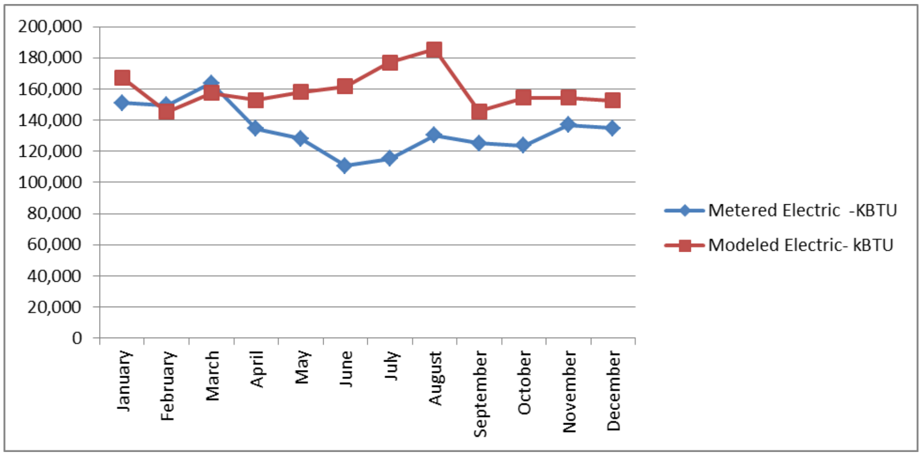
Figure 28-Dorm 937 Fort Leonard Wood- Electrical and Natural Gas Data

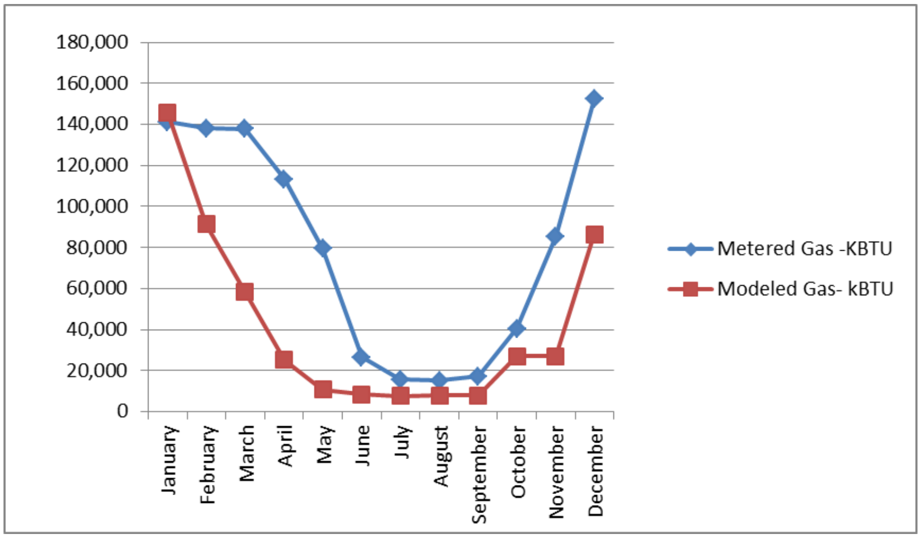




Dorm 9136 at Joint Base Lewis McChord in Washington was 78.44% accurate for electrical use compared to meter data, but had higher modeled electric data than metered data. Dorm 9136 at JBLM was 61.08% accurate in estimating natural gas usage with the energy model compared to meter data. Overall the trend between model and meter natural gas data is well aligned throughout the majority of the year; however usage is significantly higher than modeled usage from February through May and November through December (Figure 29).

Figure 29-Dorm 9136 Joint Base Lewis McChord - Electric and Natural Gas Data

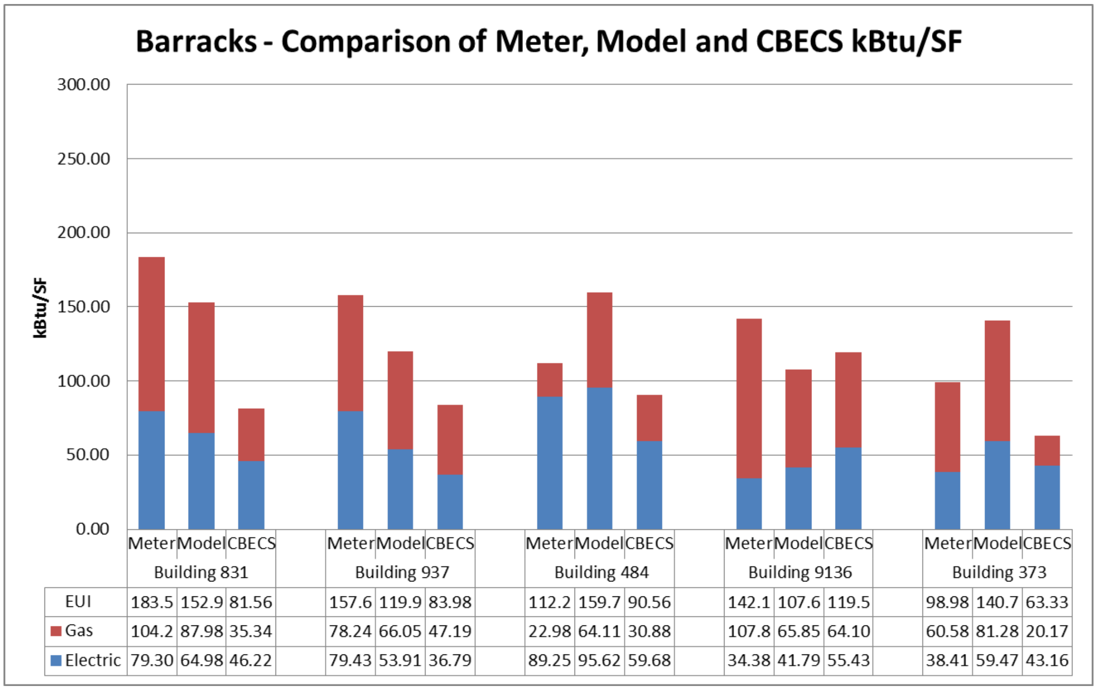




Overall, when all 5 barracks were aggregated, energy model predictions were on average 70.12% accurate with a MAPE of 29.88% for EUI predictions. The highest accuracy was with barracks 831, 937 and 9136 which were all >78% accurate. Dorms 484 and 373 were assumed to be 100% occupied throughout the year, and this is not a reasonable assumption for these particular buildings upon reviewing the meter data. Similarly, barracks that were excluded from analysis also had occupancy concerns that were even more dramatic.

Comparisons of Barracks buildings to CBECS data is summarized in Figure 30. CBECS data for dorms was not useful for comparisons due the small sample of dorms in the 2003 CBECS survey. As a result CBECS values are based on larger criteria of "lodging" within each climate zone in order to have sample sizes >10 for CBECS values. Additionally, since the 2003 survey, we have seen an explosion in the use of personal devices such as laptops and tablets, associated increases in plug loads would not have been observed in 2003.

Figure 30-Comparisons of Meter and Model EUI to CBECS for Barracks



	Building 831			Building 937			Building 484			Building 9136			Building 373		
	Meter	Model	CBECS	Meter	Model	CBECS	Meter	Model	CBECS	Meter	Model	CBECS	Meter	Model	CBECS
EUI	183.5	152.9	81.56	157.6	119.9	83.98	112.2	159.7	90.56	142.1	107.6	119.5	98.98	140.7	63.33
Gas	104.2	87.98	35.34	78.24	66.05	47.19	22.98	64.11	30.88	107.8	65.85	64.10	60.58	81.28	20.17
Electric	79.30	64.98	46.22	79.43	53.91	36.79	89.25	95.62	59.68	34.38	41.79	55.43	38.41	59.47	43.16

Conclusion

The REM workflow is a reasonable approach to predicting electric, natural gas and EUI in barracks buildings that have consistent occupancy throughout the year. Variable occupancy can skew the data significantly.

If barracks buildings are going to be utilized in REM workflows, users should understand that the energy models assume 100% occupancy. Reduced occupancy levels can be varied in GBS (i.e. 75% occupancy, 50% occupancy); however seasonality of reduced occupancy cannot be accounted for in the building energy model. Given the highly variable nature of DoD barracks and lack of available information on occupancy levels through the year, the REM workflow for barracks may not be ideal, unless users are comfortable with the assumptions described above.

6.1.3 Specialty Use Buildings Subset

In addition to offices and barracks, researchers sampled five specialty use buildings including a dining cafeteria, school, fire station, automotive facility and a gym. All buildings were under 45,000 GSF and were located at Seymour Air Force Base, with the exception of one gym in Fort Leonard Wood, MO.

Table 13-Specialty Use Buildings - Photos

 Building 3650 – Cafeteria- Seymour AFB – North Carolina	 Building 4103- School – Seymour AFB– North Carolina
 Building 4537- Automotive Facility - Seymour AFB– North Carolina	 Building 4601 – Firestation – Seymour AFB – North Carolina
 Building 640 – Gym- Fort Leonard Wood, MO	

Overall, energy models for these aggregate specialty use buildings were an average of 80.58% accurate for electricity estimates, with a MAPE of 15.72%, indicative of a good forecast. Energy models were an average of 70.80% accurate for natural gas predictions, with a MAPE of 29.20%, indicating a reasonable forecast. Overall, specialty use building energy models were an average of 85.58% accurate for predicting EUI with a MAPE of 14.42%, signifying a good forecast (Table 14).

Figure 31-Mean Absolute Error in Specialty Use Buildings

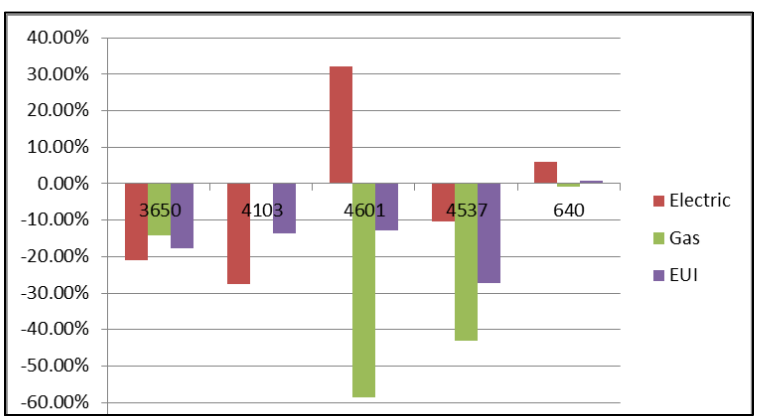
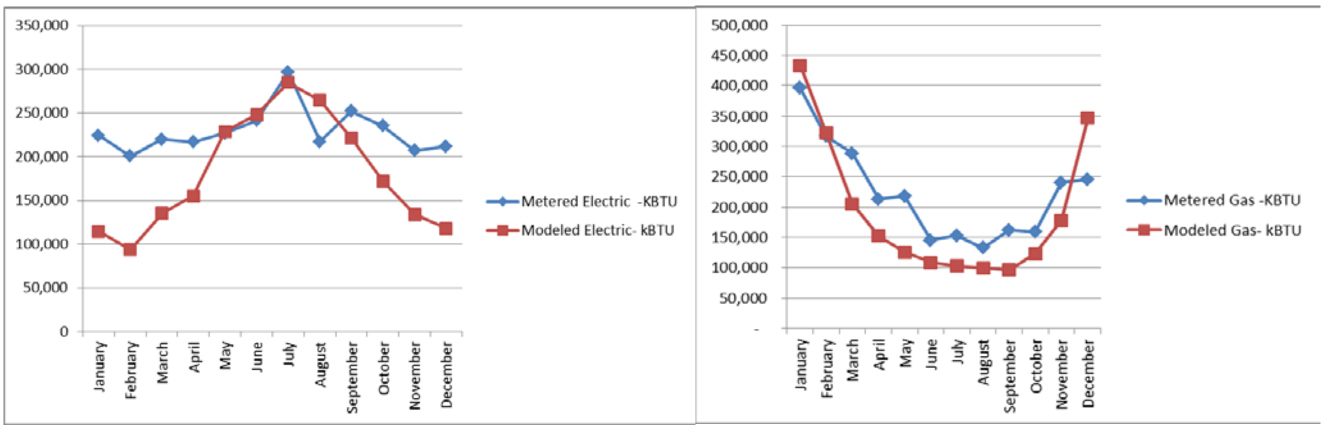


Table 14-Summary Data for Specialty Use Buildings

Building Number	Building Type - Modeled	Division	Gross Floor Area-Modeled Conditioned Space	State	kWh From Meter	kWh from Model (GBS)	Mean Bias Error-Model Vs Meter - Electric	Accuracy Model Vs Meter - Absolute (Elec)	MMBTU From Meter	MMBTU From Model (GBS)	Mean Bias Error- Model Vs Meter - Gas	Accuracy Model Vs Meter Absolute (Gas)	Total Metered EUI (kBtu/SF)	Total Modeled EUI (kBtu/SF)	Mean Bias Error- Modeled Vs Metered - EUI (kBtu/SF)	Accuracy Model Vs Meter - Absolute (EUI)
3650	Cafeteria	Air Force	28,013	NC	805,718	636,028	-21.06%	78.94%	2669.9	2294.736	-14.05%	85.95%	193.47	159.41	-17.61%	82.39%
4103	School	Air Force	25,851	NC	650,258	470,667	-27.62%	72.38%	0	310.1262			85.85	74.14	-13.64%	86.36%
4601	Firestation	Air Force	43,187	NC	564,493	746,343	32.21%	67.79%	1,890	781.9529	-58.63%	41.37%	88.37	77.09	-12.77%	87.23%
4537	Automotive Facility	Air Force	38,700	NC	613,119	549,983	-10.30%	89.70%	2,203	1251.493	-43.19%	56.81%	111.00	80.84	-27.17%	72.83%
640	Gym	Army	20,889	MO	287,682	304,660	5.90%	94.10%	2652.367	2627.316	-0.94%	99.06%	173.98	175.55	0.91%	99.09%
Summary Data for Speciality Use Buildings							Avg Accuracy	80.58%			Avg Accuracy	70.80%			Avg Accuracy	85.58%
							MAPE	19.42%			MAPE	29.20%			MAPE	14.42%
							STDEV	11.18%			STDEV	26.39%			STDEV	9.47%
							CoV	13.87			CoV	37.28			CoV	11.06
							MFE	6.56			MFE	10.57			MFE	17.13
							MAD	13.42			MAD	15.37			MAD	17.76

The energy model for Building 3650 (a dining cafeteria) was approximately 78.94% accurate (-21.06% MBE) for model predictions of electricity usage and 85.95% accurate for natural gas predictions (-14.05% MBE) (Figure 31). The electric trend profile was well aligned in shape and tightly aligned in values during the months of May, June and July. There was a sharp unexplained dip in metered electricity usage in August, followed by an increase in September. Natural gas model data for building 3650 aligns well with the meter data profile, with the exception of a deviation during the month of December when model estimates are significantly higher. This difference may be due to decreased usage during the month, perhaps due to troop deployments (Figure 32).

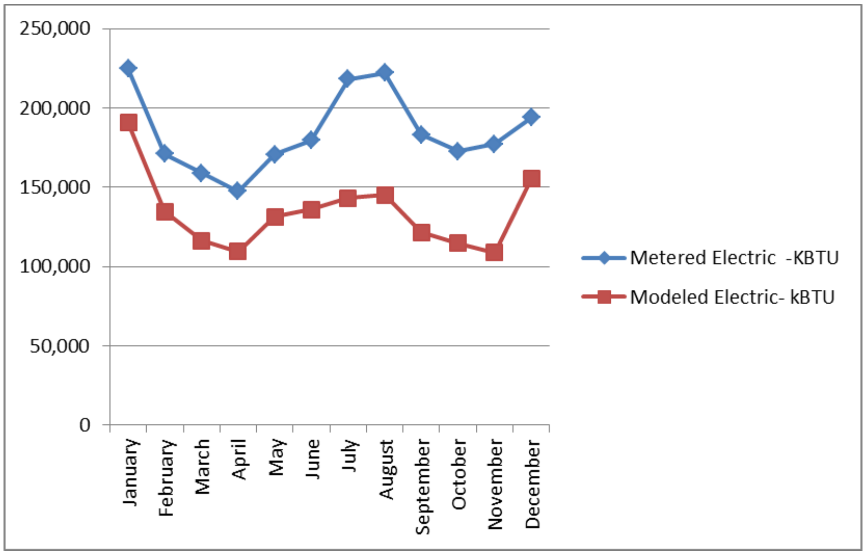
Figure 32-Cafeteria 3650, Seymour Air Force Base



Building 4103 is an all-electric school at Seymour Air Force Base. Electric estimates are 72.38% accurate (-27.62% MBE) compared to meter data and 86.36% accurate for overall EUI estimates compared to metered EUI (-13.64% MBE).

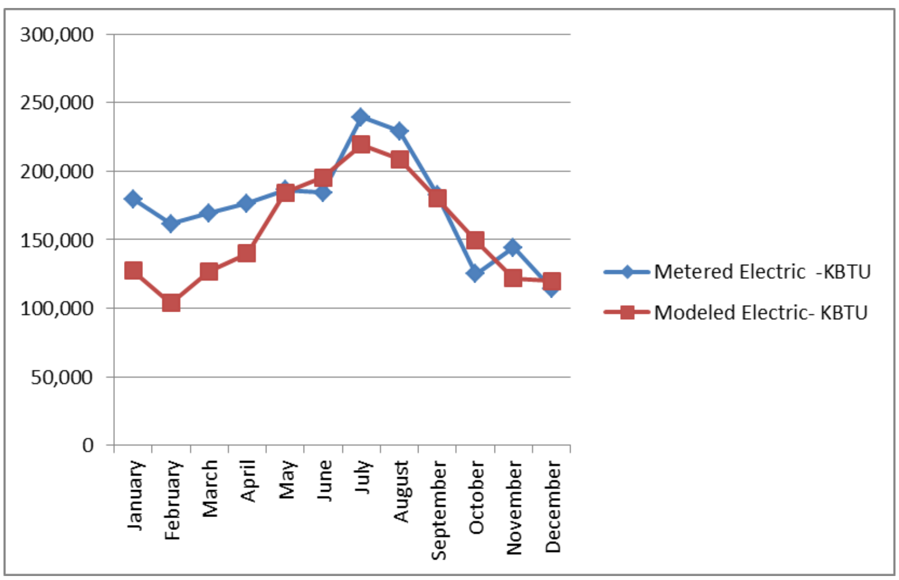
Green Building Studio models did not pick up the fact that the building was all electric and while recognized the electric HVAC, modeled some minor natural gas usage associated with hot water heating. Close correlation with overall EUI may be attributed to removal of HVAC gas use related calculations. Electric meter data was consistently higher than modeled electric data; however the trend profiles are in alignment with the exception of sharp increases in metered usage in July and August, perhaps due to space cooling (Figure 33).

Figure 33-School Building 4103, Seymour Air Force Base

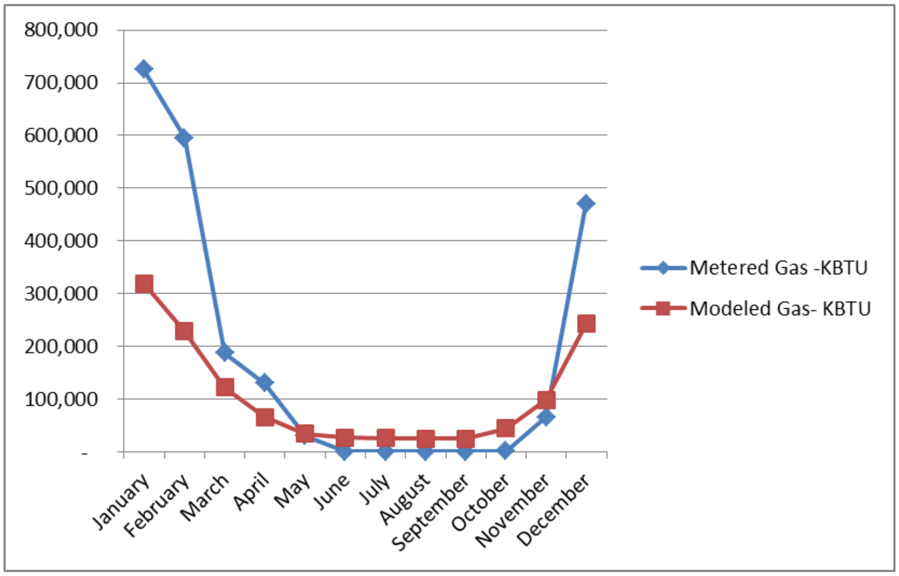


Building 4537 is an automotive facility at Seymour Air Force base. The building energy model was approximately 89.70% accurate for electric usage predictions (-10.3% MBE). The trend profile was well aligned in shape throughout the year. The model did not successfully predict gas usage, with only 56.81 % accuracy, and a MBE of -43.19%. The trend profile aligned in shape throughout the year, however metered gas usage was significantly higher than modeled usage in December, January and February. These extreme differences between predicted and actual gas values in the winter months negatively affected accuracy, as all other months were closely aligned (Figure 34).

Figure 34-Automotive Facility 4537, Seymour Air Force Base

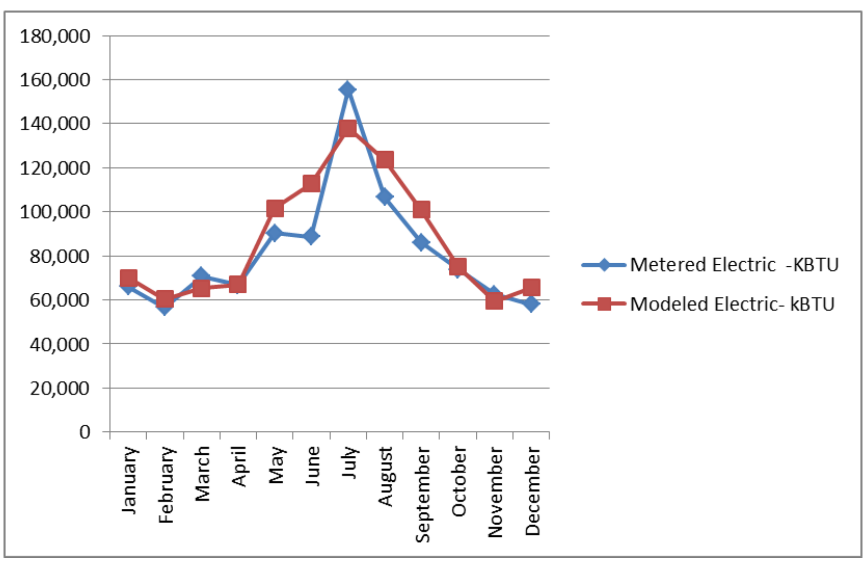


Automotive Facility 4537, Seymour Air Force Base

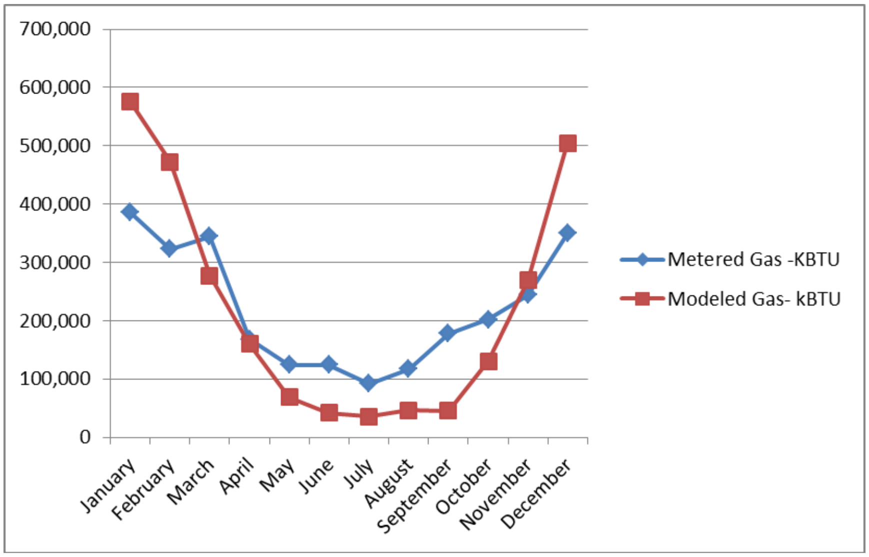


Building 640 is a gym at Fort Leonard Wood, MO. The building energy model was approximately 94.10% accurate for electric usage predictions (5.9% MBE). The trend profile was well aligned in shape throughout the year. The model did successfully predict natural gas usage, with only 56.81 % accuracy, and a MBE of -43.19%. The trend profile aligned in shape throughout the year, however metered natural gas usage was significantly higher than modeled usage in December, January and February. These extreme differences between predicted and actual gas values in the winter months negatively affected accuracy, as all other months were closely aligned (Figure 35).

Figure 35-Gym Building 640, Fort Leonard Wood

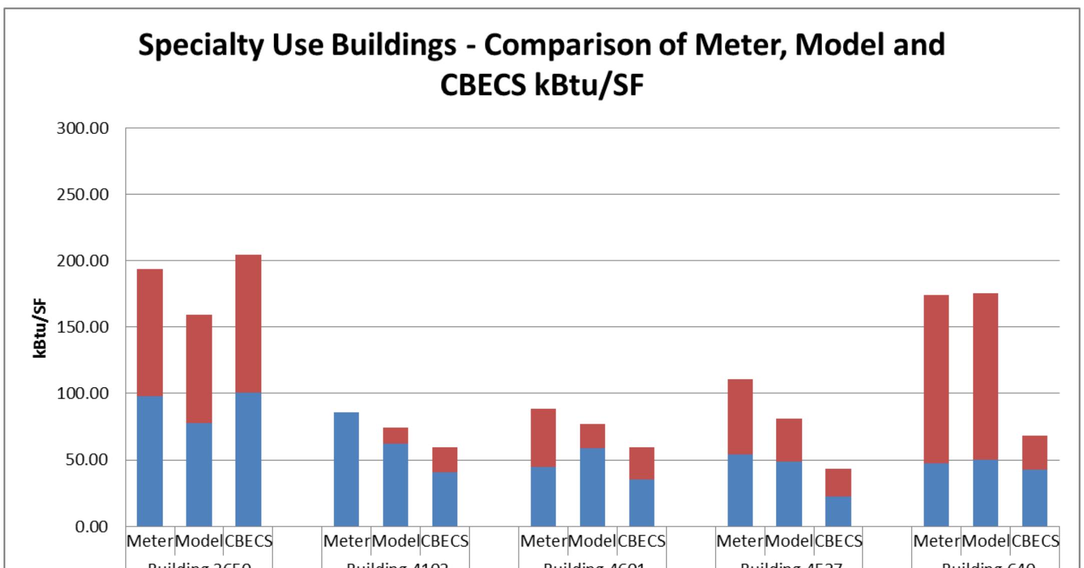


Gym Building 640, Fort Leonard Wood



Given the specialized building types in this subset, and the limited number of building types in the CBECS database, comparison to CBECS is likely unreliable for these buildings (Figure 36).

Figure 36-Comparisons of Meter and Model EUI to CBECS for Specialty Use Buildings



	Building 3650			Building 4103			Building 4601			Building 4537			Building 640		
	Meter	Model	CBECS	Meter	Model	CBECS	Meter	Model	CBECS	Meter	Model	CBECS	Meter	Model	CBECS
EUI	193.4	159.4	204.2	85.85	74.14	59.37	88.37	77.09	59.51	111.0	80.84	43.16	173.9	175.5	68.35
Gas	95.31	81.92	103.4	0	12	18.59	43.76	18.11	24.22	56.93	32.34	21.13	126.9	125.7	25.60
Electric	98.17	77.49	100.8	85.85	62.14	40.78	44.61	58.98	35.29	54.07	48.50	22.03	47.00	49.78	42.75

Conclusion

The REM workflow was a good methodology for forecasting electric and EUI for specialty use buildings based on mean absolute percentage error (MAPE) values between 11-20%. Further, there were close correlations in trend profiles in monthly data charts. The workflow was reasonable at predicting natural gas usage in specialty use buildings as indicated by MAPE value of 29.2%.

6.2 VARIANCE IN MONTHLY CONSUMPTION (BILLING HISTORY)

The calibrated simulation approach in this study involves use of the Green Building Studio program and DOE 2.2 engine to model energy use of existing buildings in pre-retrofit conditions and then checked against actual measured values. Researchers compared monthly utility costs between the simulated energy values and actual (metered) energy values using utility rates provided by installation POCs. Utility rates and usage were used as a proxy for utility bills, with the assumption that tariffs are included in the rates provided. Researchers calculated the Coefficient of Variation of the Root Mean Squared Error (CV)RMSE)) for each building. Additionally, for comparison CVRMSE was calculated using energy consumption as opposed to energy costs.

Buildings were not modeled again, refined or recalibrated to get within 15% of CVRMSE, rather the data is presented as a picture of how baseline models performed relative to measured values and can allow identification of which buildings are closest to acceptable calibration thresholds guided by under the ASHRAE Guideline 14-2002.

Three building models were within 15% of CVRMSE for billing including Building 1 at Peterson AFB, Building 470 at Fort Leonard Wood, and CERL Building 2. Two additional buildings were within 20% CVRMSE for billing data, including Peterson AFB Building 350 (18.73% CVRMSE) and Building 4601 at Seymour AFB (18.84% CVRMSE). Only one building, 4103 at Seymour AFB was within 20% CVRMSE for energy usage. The five buildings within 20% CVRMSE for billing were used to explore ECMs through Design Alternatives in Green Building Studio.

Table 15-CVRMSE Data

BUILDING - State	Cost per therm	Cost per kWh	Total Cost % Difference	CVRMSE Monthly Billing	CVRMSE Monthly Energy Usage
B1 - CO	$0.66	$0.06	-23.73%	10.39%	34.49%
350 - CO	$0.66	$0.06	8.64%	18.73%	28.94%
1100- CA	$1.53	$0.20	33.64%	34.87%	34.94%
110 - FL	$0.70	$0.10	0.50%	27.23%	33.87%
470 - MO	$0.89	$0.09	-12.61%	14.47%	28.00%
3369 - WA	$1.08	$0.04	-4.60%	21.62%	22.35%
Cerl1 _IL	$0.84	$0.07	-30.83%	32.33%	40.25%
Cerl2 - IL	$0.84	$0.07	-11.17%	12.60%	21.92%

581- FL	$0.70	$0.10	-19.58%	39.81%	41.06%
4421 - NC	$0.85	$0.07	-22.82%	26.71%	33.90%
Cerl3 - IL	$0.84	$0.07	-34.33%	37.66%	50.19%
1345- CO	$0.66	$0.06	-19.28%	24.66%	27.86%
1485 - CO	$0.66	$0.06	4.62%	31.89%	54.82%
Offices				25.61%	34.82%
831 - MO	$0.89	$0.09	-17.31%	37.12%	31.65%
937 - MO	$0.89	$0.09	-28.02%	31.21%	26.09%
484- FL	$0.70	$0.10	17.29%	30.57%	59.24%
9136- WA	$1.08	$0.04	-23.37%	54.27%	55.20%
373 - ME	$1.32	$0.09	45.67%	48.96%	46.63%
Barracks				40.43%	43.76%
3650 - NC	$0.85	$0.07	-18.99%	23.08%	21.09%
4103- NC	$0.85	$0.07	-21.58%	23.34%	16.78%
4601- NC	$0.85	$0.07	5.13%	18.84%	24.83%
4537- NC	$0.85	$0.07	-20.60%	39.32%	55.21%
640- MO	$0.89	$0.09	2.65%	22.44%	33.80%
Specialty Use Buildings				25.40%	30.34%
Aggregated				25.55%	33.57%

6.3 TESTING THE REM PROCESS FOR DESIGN ALTERNATIVES TO MODEL POTENTIAL ENERGY SAVINGS

A subset of 5 buildings was selected based upon falling within 20% CVRMSE for monthly utility costs and design alternatives for energy conservation were explored for these buildings. PES analyses tables and charts automatically generated in Green Building Studio guided researchers in assessing Energy Conservation Measures.

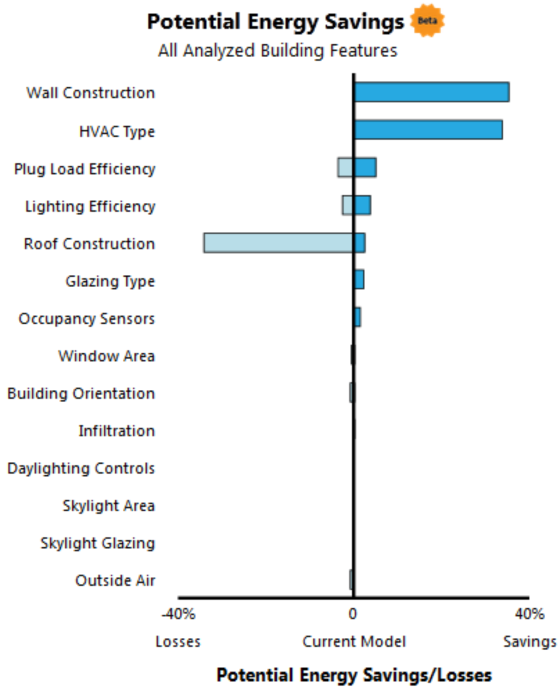
Estimated Savings from ECMs is expressed as:

- *Metered energy saved = Metered baseline (kWh, therms, kBtu) –ECMpost (kWh, therms, kBtu)*
- *Modeled energy saved =Modeled baserun (kWh, therms, kBtu) –ECMpost (kWh, therms, kBtu)*
- *Metered Cost savings = Metered baseline $ – ECMpost $*
- *Modeled Cost savings =Modeled baserun $ – ECMpost $*

6.3.1 Design Alternatives - CERL Building 2

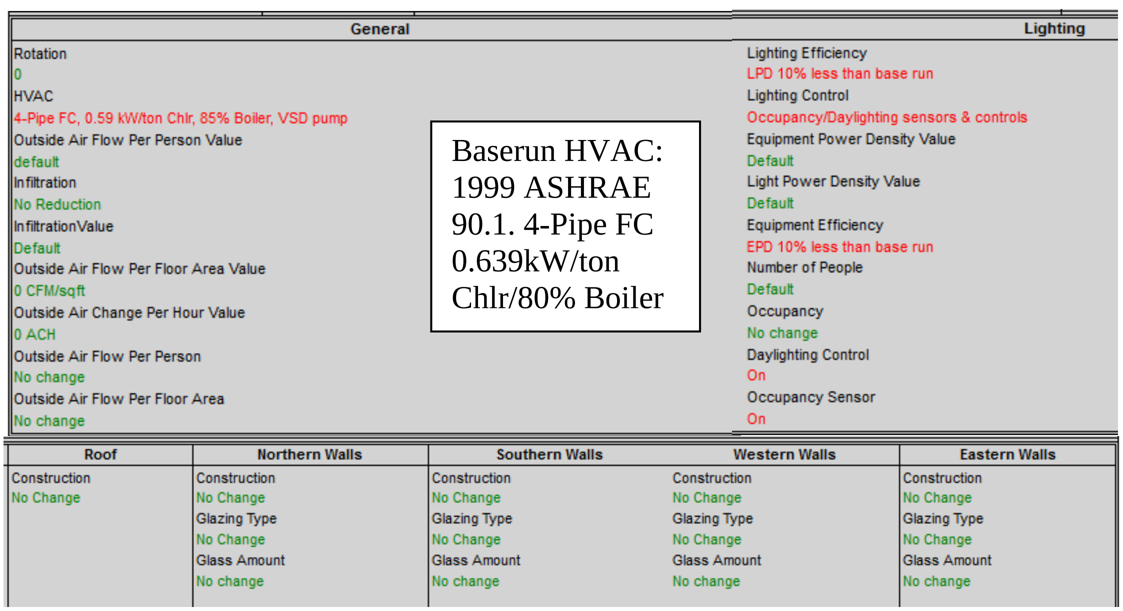
For CERL Building 2, an office in Champaign, IL had a CVRMSE value of 12.6%. PES analyses indicated that the highest energy savings could be gained by modifying wall construction, HVAC type, and plug load and lighting efficiency (Figure 37).

Figure 37-Potential Energy Savings Chart for CERL Building 2



A basic package set of measures explored upgrading the HVAC system while utilizing the infrastructure of the existing 4 pipe fan coil system, reducing lighting power density (LPD) and equipment power density (EPD) by 10% and installing occupancy sensors and daylighting controls (in red in Figure 38).

Figure 38-Basic Package Upgrades for CERL B2



An advanced package included all measures included in the basic package, and also included addition of insulation to the massive brick walls which was the number one recommended improvement, but also potentially the most costly.

Figure 39-Advanced Package Upgrades for CERL B3

General	Lighting
Rotation	Lighting Efficiency
0	LPD 10% less than base run
HVAC	Lighting Control
4-Pipe FC, 0.59 kW/ton Chlr, 85% Boiler, VSD pump	Occupancy/Daylighting sensors & controls
Outside Air Flow Per Person Value	Equipment Power Density Value
default	Default
Infiltration	Light Power Density Value
No Reduction	Default
InfiltrationValue	Equipment Efficiency
Default	EPD 10% less than base run
Outside Air Flow Per Floor Area Value	Number of People
0 CFM/sqft	Default
Outside Air Change Per Hour Value	Occupancy
0 ACH	No change
Outside Air Flow Per Person	Daylighting Control
No change	On
Outside Air Flow Per Floor Area	Occupancy Sensor
No change	On

Baserun HVAC: 1999 ASHRAE 90.1. 4-Pipe FC 0.639kW/ton Chlr/80% Boiler

Baserun walls: High Mass, No Insulation

Roof	Northern Walls	Southern Walls	Western Walls	Eastern Walls
Construction	Construction	Construction	Construction	Construction
No Change	Massive Wall with High Insulation	Massive Wall with High Insulation	Massive Wall with High Insulation	Massive Wall with High Insulation
	Glazing Type	Glazing Type	Glazing Type	Glazing Type
	No Change	No Change	No Change	No Change
	Glass Amount	Glass Amount	Glass Amount	Glass Amount
	No change	No change	No change	No change

The basic package set of measures yielded energy savings of 27.02% and $20,723 cost savings compared to metered energy usage, and 8.75% compared to modeled usage and $9,636 in costs savings compared to the modeled baserun.

Adding wall insulation under the Advanced Package yielded an additional 26% energy savings (53.25% total savings) and an additional $19,080 ($39,803 total) in annual cost savings compared to the metered baseline. Differences seen between modeled and metered savings are due to energy usage differences between the runs, even though they fall within 15% CVRMSE calibration criteria.

Table 16-Design Alternatives Packages for Energy Savings – CERL B2

RUN		EUI - kBtu/ ft²	Cost Electric at .066 / kWh	Cost Fuel at .84/therm	Cost Energy	Electric kWh	Electric KBTU	Fuel	Fuel KBTU	TOTAL KBTU	Carbon Emissions (tons)
CERL 2 Metered Baseline		156.2	64,677	35,283	99,960	979,952	3,344,576	42003.5	4,200,350	7,544,926	
CERL 2 Modeled Baserun		124.9	67,509	21,364	88,873	1,022,858	3,491,013	25,434	2,543,372	6,034,384	1,061.10
ECM Basic Package		114	58,312	20,925	79,237	883,510	3,015,420	24,911	2,491,100	5,506,520	914.1
ECM Advanced Package		73	53,969	6,187	60,156	817,712	2,790,851	7,366	736,600	3,527,451	741.4
Basic Package Savings -Modeled Baserun	Savings	11	$9,197	$439	$9,636	139,348	475,593	523	52,272	527,865	147
	% Decrease	8.75%	13.62%	2.06%	10.84%	13.62%		2.06%			13.85%
Advanced package savings -Modeled Baserun	Savings	52	$13,540	$15,177	$28,716	205,146	700,162	18,068	1,806,772	2,506,933	320
	% Decrease	41.55%	20.06%	71.04%	32.31%	20.06%		71.04%			30.13%
Basic Package Savings -Metered Baseline	Savings	42	$6,365	$14,358	$20,723	96,442	329,157	17,093	1,709,250	2,038,407	
	% Decrease	27.02%	9.84%	40.69%	20.73%	9.84%		40.69%			
Advanced Package Savings -Metered Baseline	Savings	83	$10,708	$29,096	$39,803	162,240	553,725	34,638	3,463,750	4,017,475	
	% Decrease	53.25%	16.56%	82.46%	39.82%	16.56%		82.46%			
ADVANCED PACKAGE produced additional savings of:		26.25%	6.71%	41.77	19.09%						
ADVANCED PACKAGE Annual Cost Savings of:			$4343	$14,738	$19,080						

6.3.2 Design Alternatives – Building 1, Peterson AFB

Peterson B1, an office in Colorado Springs, CO had a CVRMSE of 10.39%. A basic package guided by Potential Energy Savings Results (Figure 40), explored measures including reducing LPD and EPD by 10% each and adding occupancy and daylighting sensors and controls.

Figure 40-Potential Energy Savings Chart for Building 1 – Peterson AFB

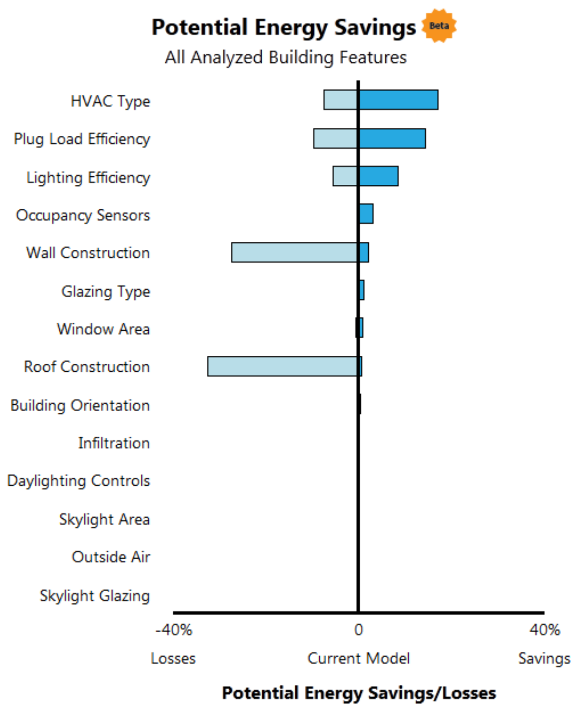
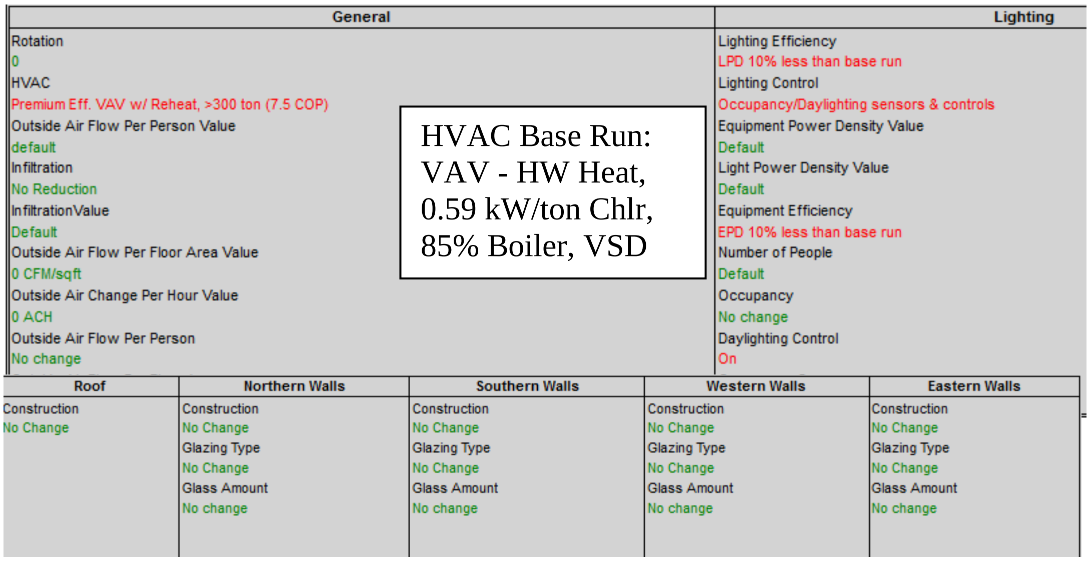


Figure 41-Basic Package Design Alternative Measures

Lighting Efficiency
LPD 10% less than base run
Lighting Control
Occupancy/Daylighting sensors & controls
Equipment Power Density Value
Default
Light Power Density Value
Default
Equipment Efficiency
EPD 10% less than base run
Number of People
Default
Occupancy
No change
Daylighting Control
On
Occupancy Sensor
On

There were no high priority envelope measures indicated by the Potential Energy Savings Chart, thus an advanced package explored basic package measures and also included a HVAC change to premium efficiency VAV with reheat.

Figure 42-Advanced Package Design Alternative Measures



Lighting, equipment and control improvements yielded a 40% improvement in EUI over metered baseline values and a 12.81 % improvement over EUI from the modeled baserun. Annual cost savings were $105,000 from the metered baseline, and $17,727 from the modeled baserun. This discrepancy is linked to differences between metered and modeled energy estimates, despite CVRMSE values within 15%.

With HVAC improvements added to the improvements identified, facility owners may realize an additional $28,828 in annual cost savings ($134,463 total) and 1.95% improvement in EUI (41.95% total) over metered values.

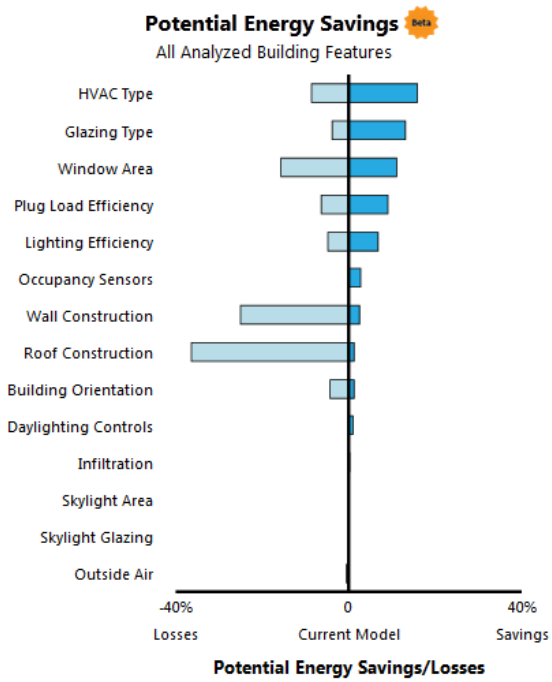
Table 17-Design Alternatives Packages for Energy Savings – Peterson B1

RUN		EUI - kBtu/ ft^2	Cost Electric at .06 /kWh	Cost Fuel at .66 kWh	Cost Energy	Electric kWh	Electric KBTU	Fuel - therms	Fuel KBTU	TOTAL KBTU	Carbon Emissions (tons)
Peterson 1 Metered Baseline		87.3	$335,425	$36,458	$371,883	5,590,418	19,080,097	55240	5,524,000	24,604,097	
Peterson 1 Modeled Baseline		60.1	$275,591	$8,386	$283,976	4,593,182	15,676,531	12,705	1,270,540	16,947,071	4206.6
ECM Basic Package		50.7	$229,115	$8,305	$237,421	3,818,588	13,032,841	12,584	1,258,400	14,291,241	3368.7
ECM Basic Package - no HVAC		52.4	$233,013	$9,935	$242,948	3,883,549	13,254,553	15,053	1,505,300	14,759,853	3453.1
Basic Package - NO HVAC - Modeled Baserun	Savings from Original Run	8	$42,578	-$1,549	$41,029	709,633	2,421,978	-2,348	-234,760	2,187,219	754
	% Decrease from Original Run	12.81%	15.45%	-18.48%	14.45%	15.45%					17.91%
Advanced Package Savings - Modeled Baserun	Savings from Original Run	9	$46,476	$80	$46,556	774,594	2,643,690	121	12,140	2,655,830	838
	% Decrease from Original Run	15.64%	16.86%	0.96%	16.39%	16.86%					19.92%
Basic Package - NO HVAC - Metered Baseline	Savings from Original Run	35	$102,412	$26,523	$128,936	1,706,869	5,825,544	40,187	4,018,700	9,844,244	
	% Decrease from Original Run	40.00%	30.53%	72.75%	34.67%	30.53%					
Advanced Package Savings - Metered Baseline	Savings from Original Run	37	$106,310	$28,153	$134,463	1,771,830	6,047,256	42,656	4,265,600	10,312,856	
	% Decrease from Original Run	41.95%	31.69%	77.22%	36.16%	31.69%					
Adding HVAC produced additional savings of:		1.95%	1.16%	4.47%	1.49%	1.16%					
Additional Annual Cost Savings of:			$3,898	$1,630	$5,527						

6.3.3 Design Alternatives for Fort Leonard Wood- Building 470

Office building number 470 at Fort Leonard Wood, MO had a CVRMSE value of 14.47% between simulated and metered monthly cost data. PES analyses indicated that greatest savings may be gained from upgrading HVAC, upgrading glazing, altering window area and improving plug load efficiency and lighting efficiency (Figure 43).

Figure 43-Potential Energy Savings for Fort Leonard Wood – Building 470



It was determined that changing window area was impractical and that was removed from consideration. Researchers thus investigated a basic package that included 10% improvement to equipment and lighting efficiency, daylighting and occupancy controls and HVAC equipment improvements (Figure 45). Researchers selected an 11.3 EER packaged VAV system which offers a slight improvement in efficiency over the current system, but does not require an overhaul of the existing HVAC infrastructure. Existing windows are double-pane, thus upgrades to these windows were considered as an Advanced Package item. Given that two identified improvements, HVAC and Window glazing have been upgraded in the building relatively recently, these were assessed iteratively in addition to basic package measures as moderate and advanced packages (Figures 45 and 46).

Exploration of design alternatives indicated that the basic package of ECMs including lighting efficiency, equipment efficiency and control improvements yielded a 31.79% improvement in EUI and cost of $73,067over metered baseline values, a 9.7 % improvement in EUI and $13,763 in savings from the modeled baserun (Table 18). Adding HVAC improvements decreased EUI by an additional 6.24% and resulted in an additional $9,506 in cost savings ($82,573 total) above the basic package reductions for the metered baseline. The combination of HVAC

improvements and window upgrades beyond the basic measures yielded a total 45.84% improvement in EUI and an estimated total annual cost savings of $90,420.

Figure 44-Basic Package Improvements – Building 470

General	Lighting
Rotation	Lighting Efficiency
0	LPD 10% less than base run
HVAC	Lighting Control
No Change	Occupancy/Daylighting sensors & controls
Outside Air Flow Per Person Value	Equipment Power Density Value
default	Default
Infiltration	Light Power Density Value
No Reduction	Default
InfiltrationValue	Equipment Efficiency
Default	EPD 10% less than base run
Outside Air Flow Per Floor Area Value	Number of People
0 CFM/sqft	Default
Outside Air Change Per Hour Value	Occupancy
0 ACH	No change
Outside Air Flow Per Person	Daylighting Control
No change	On
Outside Air Flow Per Floor Area	Occupancy Sensor
No change	On

Figure 45-Moderate Package Improvements– Building 470

General	Lighting
Rotation	Lighting Efficiency
0	LPD 10% less than base run
HVAC	Lighting Control
11.3 EER Packaged VAV, 84.8% boiler heating	Occupancy/Daylighting sensors & controls
Outside Air Flow Per Person Value	Equipment Power Density Value
default	Default
Infiltration	Light Power Density Value
No Reduction	Default
InfiltrationValue	Equipment Efficiency
Default	EPD 10% less than base run
Outside Air Flow Per Floor Area Value	Number of People
0 CFM/sqft	Default
Outside Air Change Per Hour Value	Occupancy
0 ACH	No change
Outside Air Flow Per Person	Daylighting Control
No change	On
Outside Air Flow Per Floor Area	Occupancy Sensor
No change	On

HVAC Baserun: VAV>150<300 Ton 5.55 COP Chiller, 80% Blr, No Econ

Assumed

Figure 46-Advanced Package Improvements– Building 470

General	Lighting
Rotation	Lighting Efficiency
0	LPD 10% less than base run
HVAC	Lighting Control
11.3 EER Packaged VAV, 84.8% boiler heating	Occupancy/Daylighting sensors & controls
Outside Air Flow Per Person Value	Equipment Power Density Value
default	Default
Infiltration	Light Power Density Value
No Reduction	Default
InfiltrationValue	Equipment Efficiency
Default	EPD 10% less than base run
Outside Air Flow Per Floor Area Value	Number of People
0 CFM/sqft	Default
Outside Air Change Per Hour Value	Occupancy
0 ACH	No change
Outside Air Flow Per Person	Daylighting Control
No change	On
Outside Air Flow Per Floor Area	Occupancy Sensor
No change	On

Roof	Northern Walls	Southern Walls	Western Walls	Eastern Walls
Construction	Construction	Construction	Construction	Construction
No Change	No Change	No Change	No Change	No Change
	Glazing Type	Glazing Type	Glazing Type	Glazing Type
	Insulated Grey Low-e	Insulated Grey Low-e	Insulated Grey Low-e	Insulated Grey Low-e
	Glass Amount	Glass Amount	Glass Amount	Glass Amount
	No change	No change	No change	No change

Table 18-Design Alternatives Packages for Energy Savings – Fort Leonard Wood, B470

RUN		EUI - kBtu/ ft^2	Cost Electric at .09/kWh	Cost Fuel at .89/therm	Cost Energy	Electric kWh	Electric KBTU	Fuel	Fuel KBTU	TOTAL KBTU	Carbon Emissions (tons)
Metered Baseline		83.3	$145,967	$26,010	$171,977	1,621,858	5,535,402	29224.67	2,922,467	8,457,869	
Modeled Baserun		62.9	$140,779	$9,435	$150,214	1,564,214	5,338,661	10,601	1,060,139	6,398,799	1,468.30
ECM Basic Package		56.8	$88,118	$120,161	$10,792	$130,953	4,556,778	12,126	1,212,600	5,769,378	1230.1
ECM Advanced Package -with HVAC improvement		51.6	$79,283	$108,113	$10,121	$118,234	4,099,883	11,372	1,137,200	5,237,083	1081.4
ECM Advanced with HVAC and Windows		45.1	$76,085	$103,752	$5,472	$109,224	3,934,523	6,148	614,800	4,549,323	1001.5
Basic Package Savings - Modeled Baserun	Savings from Original Run	6	$20,618	-$1,357	$19,261	229,090	781,882	-1,525	-152,461	629,421	238
	% Savings	9.70%	14.65%	-14.38%	12.82%	14.65%		-14.38%		9.84%	16.22%
Moderate package savings with HVAC - Modeled Baserun	Savings from Original Run	11	$32,666	-$686	$31,980	362,959	1,238,777	-771	-77,061	1,161,716	387
	% Savings	17.97%	23.20%	-7.27%	21.29%	23.20%		-7.27%		18.16%	26.35%
Advanced Package Savings with Basic Measures, HVAC and Windows - Modeled Baserun	Savings from Original Run	18	$37,027	$3,964	$40,990	411,409	1,404,137	4,453	445,339	1,849,476	467
	% Savings	28.30%	26.30%	42.01%	27.29%	26.30%		42.01%		28.90%	31.79%
Basic Package Savings -Metered Baseline	Savings from Original Run	26	$25,806	$15,218	$41,024	286,734	978,623	17,099	1,709,867	2,688,490	
	% Savings	31.79%	17.68%	58.51%	23.85%	17.68%		58.51%		31.79%	
Moderate Package Savings with HVAC - Metered Baseline	Savings from Original Run	32	$37,854	$15,889	$53,743	420,603	1,435,518	17,853	1,785,267	3,220,785	
	% Savings	38.04%	25.93%	61.09%	31.25%	25.93%		61.09%		38.08%	
Advanced Package Savings with Basic Measures, HVAC and Windows - Metered Baseline	Savings from Original Run	38	$42,215	$20,538	$62,753	469,053	1,600,878	23,077	2,307,667	3,908,545	
	% Savings	45.84%	28.92%	78.96%	36.49%	28.92%		78.96%		46.21%	
Compared to Metered Baseline, Adding HVAC to ECM package produced additional savings of:		**6.24%**	**6.05%**	**8.25%**	**2.58%**	**7.40%**					
Additional Annual Cost Savings of:			**$8,835**	**$12,048**	**$671**	**$12,719**					
Adding HVAC and Windows to Basic Package		**14.05%**	**8.24%**	**11.24%**	**20.46%**	**12.63%**					
Additional Annual Cost Savings of:			**$12,033**	**$16,408.7**	**$5,320.42**	**$21,729.1**					

6.3.4 Design Alternatives for Building 350- Peterson AFB

Office building 350 at Peterson AFB had a CVRMSE value of 18.37%. The potential energy savings chart (Figure 47) reveal that the biggest savings can come from alterations to glazing type, plug load efficiency, window area, lighting efficiency and HVAC type.

It was determined that changes to window area are not feasible and that existing windows are double pane and tinted, although not the latest in window design. Therefore researchers explored a basic package of measures that investigated reduction in plug load and lighting power density by 10% each plus the addition of occupancy sensors (Figure 48). The PES analysis indicated that HVAC upgrades presented low opportunity for energy savings, particularly since it would involve under floor air distribution and significant modifications to the existing infrastructure. HVAC upgrades were therefore not explored for this building.

Figure 47-Potential Energy Savings Chart for Peterson B 350

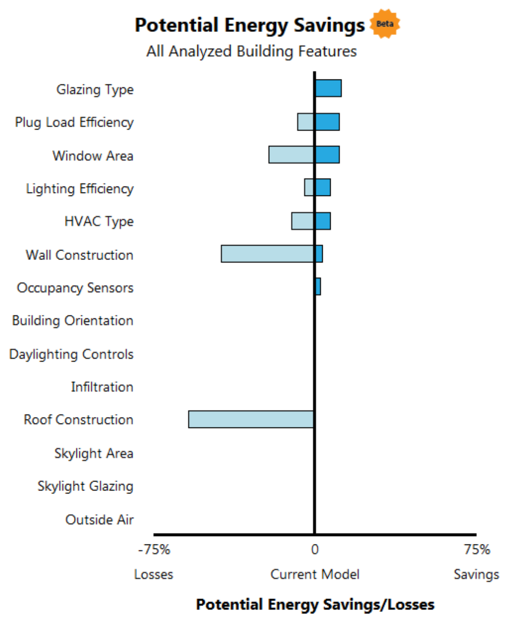


Figure 48-Basic Package Improvements B350

Lighting
Lighting Efficiency
LPD 10% less than base run
Lighting Control
Occupancy/Daylighting sensors & controls
Equipment Power Density Value
Default
Light Power Density Value
Default
Equipment Efficiency
EPD 10% less than base run
Number of People
Default
Occupancy
No change
Daylighting Control
Off
Occupancy Sensor
On

Table 19-Design Alternatives Packages for Energy Savings – Peterson AFB, Building 350

RUN		EUI - kBtu/ft²	Cost Electric at .06/kWh	Cost Fuel at .66/therm	Annual Cost - Energy	Electric kWh	Electric kBtu	Fuel Therms	Fuel kBtu	TOTAL kBtu	Carbon Emissions (tons)
Metered Baseline		58.9	$103,688	$18,964	$122,652	1,728,137	5,898,132	28733	2,873,363	8,771,495	
Modeled Baserun		61.4	$122,774	$10,639	$133,413	2,046,233	6,983,793	16,120	1,611,969	8,595,762	1,933.80
ECM Basic Package		56.8	$102,492	$12,254	$114,747	1,708,206	5,830,107	18,567	1,856,700	7,686,807	1583.5
Basic Package Savings - Modeled Baserun	Savings from Original Run	5	$20,282	-$1,615	$18,666	338,027	1,153,685	-2,447	-244,731	908,955	350
	Percent Savings	7.49%	16.52%	-15.18%	13.99%	16.52%		-15.18%		10.57%	18.11%
Basic Package Savings - Metered Baseline	Savings from Original Run	2	$1,196	$6,710	$7,906	19,931	68,025	10,167	1,016,663	1,084,688	
	Percent Savings	3.64%	1.15%	35.38%	6.45%	1.15%		35.38%		12.37%	

Exploration of basic measures within Green Building Studio Design Alternatives revealed that improving LPD by 10 % and EPD by 10%, plus adding occupancy sensors is estimated to improve EUI by 3.64% and reduce energy costs by $7,906 annually compared to metered data for the building. Improvements compared to the modeled baserun indicated an improvement of 7.49% for EUI, and annual cost savings of $18,666 (Table 19).

6.3.5 Design Alternatives for Seymour AFB Building 4601

Building 4601 is a fire station at Seymour Air Force base in North Carolina and had a CVRMSE value of 18.84%. The Potential Energy Savings chart indicated that the highest energy savings can come from upgrades to HVAC type, wall construction, glazing type, lighting power density, equipment power density and window area (Figure 49). The HVAC system that indicated improvement was an under floor air distribution system, which was not considered feasible for this building.

A basic package of measures explored 10% improvement to lighting efficiency (LPD 10% less than base run), 10% improvement to equipment efficiency (EPD 10% less than base run) and the addition of occupancy sensors (though they showed only marginal savings on the Potential Energy Savings chart. Window glazing could be improved from dual pane (baseline) to reflective, insulated, low E windows in a design alternative (Figure 50). Exploration of basic measures within Green Building Studio Design Alternatives helped improve EUI by 8.40% against the modeled baserun and 20.11% compared to the metered baseline. Advanced package upgrades yielded a modeled savings of 14.88% and 25.77% against the metered baseline (Table 20).

Figure 49-Potential Energy Savings Chart for Seymour AFB Building 4601

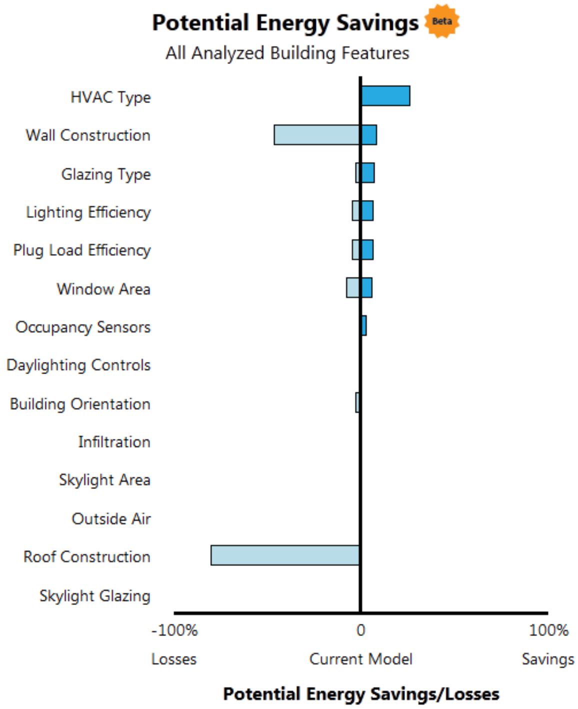


Figure 50-Basic Package Improvements – Building 4601

Lighting
Lighting Efficiency
LPD 10% less than base run
Lighting Control
Occupancy/Daylighting sensors & controls
Equipment Power Density Value
Default
Light Power Density Value
Default
Equipment Efficiency
EPD 10% less than base run
Number of People
Default
Occupancy
No change
Daylighting Control
Off
Occupancy Sensor
On

Figure 51-Advanced Package Improvements – Building 4601

General	Lighting
Rotation	Lighting Efficiency
0	LPD 10% less than base run
HVAC	Lighting Control
No Change	Occupancy/Daylighting sensors & controls
Outside Air Flow Per Person Value	Equipment Power Density Value
default	Default
Infiltration	Light Power Density Value
No Reduction	Default
InfiltrationValue	Equipment Efficiency
Default	EPD 10% less than base run
Outside Air Flow Per Floor Area Value	Number of People

Roof	Northern Walls	Southern Walls	Western Walls	Eastern Walls
Construction	Construction	Construction	Construction	Construction
No Change	No Change	No Change	No Change	No Change
	Glazing Type	Glazing Type	Glazing Type	Glazing Type
	Insulated Grey Low-e	Insulated Grey Low-e	Insulated Grey Low-e	Insulated Grey Low-e
	Glass Amount	Glass Amount	Glass Amount	Glass Amount
	No change	No change	No change	No change

Table 20-Design Alternatives Packages for Energy Savings– Seymour AFB Building 4601

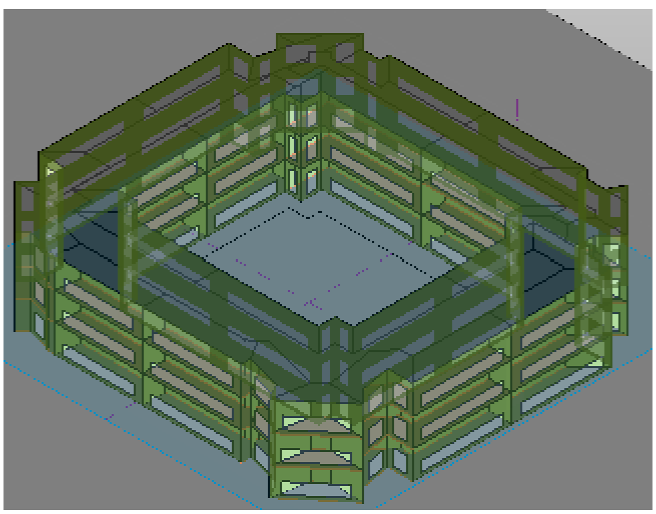
RUN		EUI - kBtu/FT²	Cost Electric at .07/kWh	Cost Fuel at .85/therm	Cost Energy-Annual	Electric kWh	Electric KBTU	Fuel	Fuel KBTU	TOTAL KBTU	Carbon Emissions (tons)
Metered Baseline		88.4	$39,515	$16,069	$55,583	564,493	1,926,615	18904.51271	1,890,000	3,816,615	
Modeled Baserun		77.1	$52,244	$6,647	$58,891	746,343	2,547,270	7,820	781,953	3,329,223	716.60
ECM Basic Package		70.6	$44,722	$7,390	$52,112	638,890	2,180,532	8,694	869,400	3,049,932	605.8
ECM Advanced Package -with Window Improvement		65.6	$42,501	$6,457	$48,958	607,156	2,072,223	7,597	759,700	2,831,923	565.2
Basic Package Savings -Modeled Baserun	Savings from Original Run	6	$7,522	-$743	$6,778	107,453	366,739	-874	-87,447	279,292	111
	Percent Savings	8.40%	14.40%	-11.18%	11.51%	14.40%		-11.18%		8.39%	15.46%
Advanced package savings -Modeled Baserun	Savings from Original Run	11	$9,743	$189	$9,932	139,187	475,047	223	22,253	497,300	151
	Percent Savings	14.88%	18.65%	2.85%	16.87%	18.65%		2.85%		14.94%	21.13%
Basic Package Savings -Metered Baseline	Savings from Original Run	18	-$5,208	$8,679	$3,471	-74,397	-253,917	10,211	1,020,600	766,683	
	Percent Savings	20.11%	-13.18%	54.01%	6.24%	-13.18%		54.01%		20.09%	
Advanced Package Savings with Windows VS Metered Baseline	Savings from Original Run	23	-$2,986	$9,611	$6,625	-42,663	-145,609	11,308	1,130,300	984,691	
	Percent Savings	25.77%	-7.56%	59.81%	11.92%	-7.56%		59.81%		25.80%	
Compared to Metered Baseline, Adding Window Improvements to ECM package produced additional savings of:		5.66%	5.62%	5.80%	5.67%						
Additional Annual Cost Savings of:			$2,221	$932	$3,154						

6.4 TIME AND COST TO ENERGY MODEL

While constructing BIM models, researchers documented the time required for model creation and energy analysis and compared time required for each workflow. These time-based tests were completed after a significant period of testing and workflow refinement. The Revit-based workflow required an average of 27.54 minutes (SD=6.75). This included time required for creation of FormIt mass models in the field, model enhancements in Revit, and energy analysis in Revit. The Vasari based workflow required an average of 17.81 minutes (SD=5.87), including integrated energy analysis natively in Vasari.

Buildings that required more time were often more complex in shape, with open courtyards or drill decks, such as dormitory building 484 in Panama City, FL (Figure 52). This building required 45 minutes to model and run energy analysis using the FormIt to Revit workflow and 35 minutes to model and run analysis with the Vasari workflow. Green Building Studio analyses required an average of 7 additional minutes for each design alternative or set of design alternatives investigated, regardless of whether the XML was recreated in Revit or Vasari.

Figure 52-Building Model



Given the data above, it can be reasonably assumed that conceptual energy models and analysis can be executed in one hour or less. It should be noted that this assumes that no travel is required, and does not include time required for installation personnel to answer questions regarding building construction and operations (the average time required for this aspect is 2 hours unless assumptions are derived from satellite photos and building knowledge instead of building documentation).

Existing methods employed by the DoD to measure energy consumption and building performance has historically been limited to benchmarking or energy audits. While benchmarking methods (such as Energy Star® Portfolio Manager or CBECS) are quick, they do not identify specific opportunities for energy-saving opportunities in buildings and are often imprecise because they are not customized to the building and are thus prone to significant error. They too, are subject to the problems with access to and availability of quality data.

Traditional energy audits might be more accurate and customized than benchmarking, but are labor intensive, expensive, and time-consuming and require a high level of expertise, therefore are not scalable across the DoD portfolio.

Three levels of energy audits are typically used: walkthrough (ASHRAE Level 1), general (ASHRAE Level 2), and investment grade (ASHRAE Level 3). Requirements for each of these levels can often lack detail and it is generally acknowledged that the levels do not have distinct boundaries (Shapiro, 2009). In general, however- audit levels may include the following:

Level 1	• Rapid assessment of building energy systems by doing a building walkthrough • Building energy benchmarking using benchmarking tools such as Energy Star® or CBECS • High-level definition of opportunities for energy conservation • Time: 1-2 days; Cost: \$500-\$700 per day [CROTON]
Level 2	• Usually follows a Level 1 audit • Detailed building survey of systems and operations • **Breakdown of energy source and end use** • **Identification of energy conservation measures** • **Range of savings for the energy conservation measures** • Identification of Operational Discrepancies • Outlining priorities for limited resources, next steps, and identification of ECMs that require additional data collection and analysis (ASHRAE Level-3) • Time: 3-10 days; Cost: \$500-\$700 per day[CROTON] or \$1,500-\$7,000 per building
Level 3	• Usually follows a Level 2 audit • **Focuses on whole-building computer simulation** • **Computer program is used to model the way the building would respond to changes in the energy systems and installation of ECMs** • Requires longer term data collection and analysis using data loggers • Whole-building computer simulation calibrated with field data • Bid-level construction cost estimating • Investment-grade, decision-making support • Time: 10-50 days; Cost: \$500-\$700 per day[CROTON]

Researchers investigated whether Rapid Energy would allow buildings to be evaluated within a shorter time and smaller budget than budget. While REM processes include the many of the benefits of Levels 1-3 energy audits, the workflow does not provide a direct match to one particular audit type, but is a closer match to the outputs of an ASHRAE Level 2 audit, with added benefits of computer simulation of a Level 3 audit.

Using the 23 buildings within the ESTCP data set, ASHRAE Level 2 audits of these buildings could cost \$179,673 based on an audit cost of \$.12 / ft^2 (Baechler et al., 2011).

With an assumed time requirement of three hours per building which would include survey collection, modeling, and energy analysis, and using the hourly rate of $100 per hour as a proxy for DoD energy manager time, trained DoD staff can create energy models for approximately $300 per building or approximately .005 per ft², representing significant cost savings (96.17%) at a total of $6,900 for the 23 buildings and time savings (96.25%) compared to auditing approaches (Table 21).

It should be noted that researchers are not recommending replacement of ASHRAE audits for DoD facilities, however given the time, expense and expertise required for ASHRAE audits, REM approaches can be used at early stages of energy analysis to determine which buildings are: poorly performing, the best candidates for retrofits and may present the best potential opportunities for energy savings, with the added benefit of computer simulation and modeled comparison of energy conservation measures.

Table 21-Comparison of REM and Level 2 Cost and Time Savings

Assuming Cost of .12 / sf for Level 2 Audit	Level 2 Audits for 23 sample buildings would cost $179,673	
Assuming time required for L2 Audits 3-10 days		
Est Cost for REM at 100/hr; 3 hr per building ; 23 buildings	$6,900.00	$.0046 per sf
Cost Savings per SF over L2 Audits	96.17%	
Time Savings Low End (hours)	87.50%	
Time Savings High End (hours)	96.25%	

6.5 QUALITATIVE PERFORMANCE OBJECTIVES

6.5.1 Ease of learning technology, ease of use and expertise required

Autodesk has recently begun technology transfer associated with the ESTCP Rapid Energy Modeling Demonstration Project. Researchers have assembled a training curriculum that includes a webinar, hands-on demonstration and free optional enrollment in an advanced certificate program.

Webinar

Researchers have developed curriculum to be opened to DoD personnel on November 11th. The webinar is broken out into sections that include: Rapid Energy Modeling Introduction and Benefits, Modeling Methodologies using FormIt, Vasari and Revit, and Green Building Studio. The webinar includes annotated videos with step by step instructions on how to create the models. A trial run of the webinar indicates that it can be delivered in 2.5 hours. The webinar will be made available to DoD personnel via the web. Webinar notes and accompanying videos will also be available online.

Hands-On Training
Researchers will complete online hands-on training for a minimum of five DoD staff. To date, training has occurred with three staff and has been completed by one staff member. The training involved a two hour meeting with:

- 15 minute overview of basic Rapid Energy Modeling concepts, data input requirements, and an overview of ESTCP results
- 15 minute demo of model creation and energy analysis in Vasari, driven by Autodesk staff
- 30 minute segment where controls are passed to DoD installation staff and they re-create model, energy analysis and reports in Vasari
- 20 minute segment on Green Building Studio capabilities for design alternatives and PES analysis; Autodesk and DoD staff share and alternate computer controls
- Remainder of time for questions and contingency in the event of technical issues

Barriers to facilitating this training have arisen due to the sequester, the Government shutdown, network restrictions, travel restrictions, web-conferencing restrictions and software access restrictions. Researchers are currently investigating how to optimize web-based training for DoD staff given these constraints.

The one participant to complete training to date has been able to re-create their first simple building model and generate an energy report in 30 minutes using instructor prompts, provided curriculum and a sample data set. At the Autodesk University annual conference in December 2013, 60 participants from diverse sectors were trained on REM and completed an energy model a 75 minute hands-on lab.

Workflow Options and Ease of Use
Given the diversity of user profiles, goals, availability of building information and time, there are multiple workflows to select from, based on end goals, systems, access and user profiles.

Table 22-Comparison of Technologies Used

Program	System & Access	Functionality and Output	Limitations	User Profile
FormIt	App for iOS and Android tablets currently; browser version in beta.	Can be used to create geo-referenced and scaled conceptual building models using satellite images. Can be used at building site or in the office. Models can be brought into Revit or Vasari for further customization and energy analysis.	Requires a tablet (desktop browser version currently in beta) Does not currently have integrated energy analysis, reporting, or communication with Green Building Studio and the DOE 2 engine (feature is currently in development).	User who wants flexibility to create rapid mass models in the field or office using a tablet User who wants to build model using auto scaled image, rather than manually scaling satellite image in Revit and building entire model in Revit Requires minimal

				practice / expertise
Revit	Windows desktop software from Autodesk. Part of ELA for many Army, Navy and Air Force buildings	Can be used for conceptual mass models and conceptual energy analysis Can also be used to create detailed BIM models with building elements, interior spaces, zones, wall, window, floor constructions with unique thermal properties, as well as MEP**.** Communicates with GBS and also runs energy analysis natively in Revit. Export of energy data as XML or energy report PDF	Does not have integrated satellite mapping cannot create geo-referenced and scaled conceptual building models using satellite images without specialized add ins. Requires scaling of satellite image, jpg file or import of .rvt file from FormIt or Vasari. Number of features and views not used in REM workflows that may could confuse new users.	Revit has more functionality than FormIt or Vasari and may require more time, training and a higher level of expertise from the end-user
Vasari	Currently available for free beta windows desktop trail at AutodeskVasari.com Considered a lightweight version of Revit for energy modeling and analysis Many capabilities are in process of migration to FormIt browser-based version.	Can be used for rapid creation of conceptual mass models and energy analysis Can be used to create geo-referenced and scaled conceptual building models using satellite images. Communicates with GBS and also runs energy analysis natively in Vasari. Export of energy data as XML or energy report PDF	Cannot create detailed BIM models but mass models (.rvt files) can be brought into Revit if detailed models are desired at some point.	Simple and streamlined program for introduction to REM workflows. User can take utilize knowledge in Revit once basic skills are learned.
Green Building Studio	Autodesk subscription service, required for energy analysis in Revit and but not required for	Backend performing energy analysis in Vasari and Revit	Detailed energy analysis can be done in eQuest or EnergyPlus where	Interface takes user training and practice to navigate

	energy analysis in Vasari Driven by DOE 2.2 engine; defaults designated by ASHRAE standards and other industry sources	Web service provides additional capabilities for customization of utility rates, PES analysis, equipment and systems customization, design alternatives, renewable energy potential, exploration of data tables and other enhancements Export of energy data as XML, VRML, DOE-2, and EnergyPlus.	there is more control over equipment and schedules	successfully Extensive documentation and user help on Autodesk wikipage 30 day free trial and free subscription for students and educators

6.5.2 User Satisfaction

Survey results are pending completion of webinar and hands-on training sessions. The three personnel who have received training to date have expressed a high degree of satisfaction with results from ESTCP for their installation, the ease and speed of the workflow, and content in reports and Green Building Studio dashboards.

There is intrigue around the ability to produce rapid coarse models with acceptable results that will allow staff to do comparative runs and quickly answer questions about which parameter has the most influence on the building, such as the roof, walls, windows, etc. Staff have communicated that REM is a good way to answer questions that are often explored by DoD energy managers when initially contemplating upgrades.

6.5.3 Ability to Scale Across DoD

DoD staff will be trained using webinars and written curriculum produced during the ESTCP project. As added value, DoD staff who participated in the ESTCP demonstration have been invited to enroll in the Autodesk Building Performance Analysis (BPA) Certificate Program under a group specifically for DoD installation staff.

The program is a no-cost, online self-paced program that will help improve knowledge of building science fundamentals and for BPA. Content of the program includes eight modules involving tutorials, quizzes and software exercises.

Completion of this advanced training may take between 20-25 hours and upon completion, participants will receive a certificate and badge.

6.6 PERFORMANCE OBJECTIVE CONCLUSIONS

REM offers a rapid, scalable and transferrable methodology with good to reasonable levels of accuracy for predicting electricity, natural gas and EUI consumption in DoD buildings. Electric results were consistently higher in accuracy than gas or EUI results and researchers recommend further exploration around gas results. The project's performance metrics provided insight on accuracy and deviations, however the correlation of energy use curves and building use categories provide greater insight on accuracy of results and on variations throughout the year. Deviations observed between meter and modeled data can be used to identify which buildings are not operating as expected and should be prioritized for further investigation and considered for retrofits.

The REM workflows allow DoD facility managers and energy managers to quickly create building models based on limited information and quickly generate reports and answer questions related to building energy consumption. Additionally, using the PES chart and automatic simulations, staff can quickly see sensitivity of the building to changes in parameters, and the comparative value of modifications to HVAC, roof, walls, windows, lighting, equipment etc.

The workflow allows DoD to answer questions related to which energy conservation measures (ECMs), including combinations of measures can result in potential energy savings. The REM workflow is easy to learn and DoD facility managers can generally begin creating energy models and interpreting results after 3 hours of instruction. REM workflows can help scale energy analysis throughout the DoD at a pace that is significantly faster than ASHRAE audits that require significant expense and expertise. REM results can help DoD make informed decisions about which buildings are using the most energy, can benefit most from energy retrofits, and may be the most practical to meter and audit. This technology can also allow the DoD to meet existing energy auditing and energy management reporting requirements including EISA 2007.

Initial cultural indications are that this method is well received at the installations. While the technology is new, this process utilizes a category software tools that are familiar to installation facility asset managers (Google Earth and CAD/BIM software). The learning curve for this technology is measured in hours, and the startup fees are low. This provides support that this technology can be used in production at the installations and move beyond its current prototype status. A continuation of our technology transfer activities; with installation site visits, web presentations, in person conference presentations and collaboration with CERL and USACE CAD BIM Technology Center and other DoD energy management branches can help provide and understanding of how this technology may be applied and expand its use.

7.0 COST ASSESSMENT

Cost estimates are organized into high and low range estimates for a given site. The high range estimates assume computer hardware and would be purchased. This assumed hardware purchase is not mandatory as existing installation laptop/desktop computers can be used for the REM solution. The high range estimate also assumes software will be purchased specifically for this task. This may not be necessary as the Air Force, Navy and the Army Corps of Engineers have existing enterprise software licenses for most software titles used for REM. The software titles not covered in the enterprise agreements are available as free software downloads. The low range

cost estimates assume the utilization of existing installation hardware and the use of the existing enterprise licensed (or free) software.

7.1 COST MODEL

The REM cost model consists of the following cost element components:

Table 23-REM Cost Model

Cost Elements (Unit One)	**Data Tracked During the Demonstration**	**Estimated Costs for Installation**	**Unit Measure**
Hardware capital costs*	Typical Laptop/Desktop cost during demonstration period	$1,350	Per user
Software Costs**	COTS software fees during project demonstration	$4,590	Per Installation
Software Installation Costs	Time/Labor to install/downloaded software	$200	Per user
Operational Costs	Level of effort to model building, add operational attributes and produce energy model and reports	$300	Per building
Software Maintenance	Frequency of available software upgrades	$600	Yearly
Operator Training	Length of time for training session (1day)	$500	Per user
* Assuming no existing desktop or laptop hardware			
** Assuming no access to existing Department of Defense Enterprise Software Licenses			

Life Cycle Cost Elements

Hardware Cost Element: Existing mid-tier current computer hardware either laptop or desktop can be used for the application of this technology. A four year refresh cycle is assumed on the hardware components. This hardware is needed to run the application software and to provide access to satellite imagery of the studied buildings.

Software Cost Element: Software to process the Rapid Energy Modeling data are include the list below. No single installation will need all software listed and requirements will vary depending on the context of each installation.

Software Installation Costs: This project is primarily a software based activity with no installation of energy equipment hardware as part of the project or eventual deployment of this technology at the installations. Installation costs include the time to download and/or install the software. Satellite imagery used in this study is from free public image sources.

Software Consumable: The life cycle costs of this system will include annual software subscription fees. These fees typically are 15% of the initial purchase price of the software and are required each year that the software is utilized. These are needed to keep up with current capabilities and to maintain compatibility with all participating software.

Data Consumable: Satellite Imagery: free imagery was used for this project and proved capable for the task. The imagery is used to capture the building footprint as well as other building attributes for the REM process.

Operator Training Cost: 1 day of training per user. This training has proved effective over the web and does not require travel for the installation POC to receive the training. The training is needed to understand the operation of the software, the data collecting requirements and the data hand-offs for the REM workflow.

Life-Cycle Cost Time Frame: The lifecycle cost timeframe is four years for this project estimate.

Up Front Set Up Costs - Per Installation (High Range)

Hardware*	$1,350
Software **	$4,590
Software Installation	$200
Software Subscription	$600
Operator Training	$500

	$7,240

Up Front Set Up Costs - Per Installation (Low Range)

Hardware*	$0
Software **	$0
Software Installation	$200
Software Subscription	$600
Operator Training	$500

	$1,300

The operational costs after the up-front expenditures would be $300 per building modeled with this process multiplied by the number of buildings studied at an installation.

Operational Scaling Considerations

Our enterprise cost model is assuming one set of REM tools per installation at 185 installations as a full deployment of this technology (Table 24).

7.2 COST DRIVERS

The hardware costs and the software costs for this project are well known and reasonably predictable. The major costs have been variable costs - of collecting the operational attributes of the buildings, modeling and analyzing buildings and creating ECMs. This may well prove to be the case with a larger population of sites. Some installations have this operational information readily available. At other locations this information is in disparate sources that make collecting the information more challenging and potentially increasing costs. In these cases were this information cannot be obtained cost effectively (or at all) default ASHRAE settings are used to cap data collection costs. An additional cost driver is the number of buildings studied with the REM methodology. This is a linear progression with the per-building REM modeling costs outlined in section 7.1.

Site specific and regional issues may come into play through the interaction of the installation POC with the IT department at each installation. The installation of new software titles may require IT participation. The process to add new software titles vary per agency and per location. This is a potential cost variable to consider when deploying this technology. DoD Enterprise-wide life cycle costs for REM components are summarized in Table 24.

7.3 COST ANALYSIS AND COMPARISON

REM utilizes recently available digital 3D modeling technologies. The REM approach does not conform precisely to existing energy assessment methods making direct comparisons challenging but in the end productive. Also as there is no energy efficiency equipment installed at the installation with this demonstration project some of the life cycle cost methods are difficult to fit to this project.

A useful approach in forming a life cycle cost understanding of this technology is to compare REM to ASHRAE Energy Audits. While REM and energy audits approach the subject matter from different viewpoints with substantive differences in methodology, there is a significant overlap in the data produced, accomplishing similar asset management objectives and in the overall desired outcomes.

REM Per-Building Operational Costs Compared to ASHRAE Audits

Reported costs for detailed energy audits may vary from \$0.12 up to \$0.503 per square foot, depending on the size and complexity of the building (Baechler et al., 2011). For the purposes of this study, researchers used the low-range estimate. In this study of 23 buildings comprising 1,497,275 ft^2 of conditioned space was modeled. This yields a low-end cost of \$179,673 using the value of \$0.12 per ft^2. to conduct a Level 2 audit on the population of the studied REM buildings. In comparison, applying the REM process to this population of buildings yielded \$0.005 per ft^2. for a total cost of \$6,900 to conduct the REM process on the total population of 23 buildings, comprising 1,497,275 gross square feet.

Typical Level 2 Audit Costs	1.49m GSF (for this project)	\$179,673
REM Cost	1.49m GSF (for this project)	\$6,900

From this demonstration project the REM process has shown to be useful to in making energy management decisions. The REM process can be accomplished with personnel with less exacting expertise in energy systems, saving personnel cost and increasing the ability to scale. With the number of individuals doing energy assessments, the number of buildings studied can also increase. These characteristics of REM allow this process to be more cost effective then conducting typical Level 2 audits.

REM may also precede the standard energy audit process to act as a triage with justifiable recommendations to select the high priority buildings for more detailed study. With the ability to compare the relative merits of a variety of ECMs the REM process can act as a quick proxy for informing installations where to concentrate BLCC project cost studies and follow-on detailed actions.

Table 24-DoD Enterprise Wide Life Cycle Cost for REM Components

Life Cycle Cost for REM Components - High Range	**Unit Cost**	**Year 1 Costs**	**Year 2 Costs**	**Year 3 Costs**	**Year 4 Costs**	**Total Costs**
Revit Architecture	$4,590.00	$22,950.00	$137,700.00	$229,500.00	$459,000.00	$853,740.00
Revit Architecture Subscription	$575.00	$2,875.00	$17,250.00	$28,750.00	$57,500.00	$106,950.00
Green Building Studio*	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Vasari - **free download**	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
FormIt - **free download**	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
REM Process Training (1 day) - per student costs	$500.00	$2,500.00	$15,000.00	$25,000.00	$50,000.00	$93,000.00
Laptop - minimum system requirements	$1,350.00	$6,750.00	$40,500.00	$67,500.00	$135,000.00	$251,100.00
	$7,015.00	**$35,075.00**	**$210,450.00**	**$350,750.00**	**$701,500.00**	**$1,297,775.00**

**Complimentary Service with Revit Architecture Subscription*

Life Cycle Cost for REM Components - Low Range	**Unit Cost**	**Year 1 Costs**	**Year 2 Costs**	**Year 3 Costs**	**Year 4 Costs**	**Total Costs**
Revit Architecture	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Revit Architecture Subscription	$575.00	$2,875.00	$17,250.00	$28,750.00	$57,500.00	$106,950.00
Green Building Studio*	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Vasari - **free download**	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
FormIt - **free download**	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
REM Process Training (1 day) - per student costs	$500.00	$2,500.00	$15,000.00	$25,000.00	$50,000.00	$93,000.00
Laptop - minimum system requirements	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
	$1,075.00	**$5,375.00**	**$32,250.00**	**$53,750.00**	**$107,500.00**	**$198,875.00**

**Complimentary Service with Revit Architecture subscription*

Staffing Assumptions	
Number of Staff in Year 1	5
No of additional Staff in Year 2	30
No of additional Staff in Year 3	50
No of additional Staff in Year 4	100

8.0 IMPLEMENTATION ISSUES

To facilitate the future deployment of this technology the following topics should be considered.

8.1 METER DATA COMPARISONS

There were several issues related to implementation of the project tied to comparison of model estimates to meter data. These are germane in the execution of this demonstration pilot as a blind study, but may be of reduced significance in future deployments of this technology because often the meter data often does not exist or is unusable, and the technical confidence for this approach has been demonstrated by this project.

The results of this project recommend REM as a method to improve DoD building data availability considering the difficulty with the current building energy meter deployments at the Department of Defense. REM also helped identify meters that were not functioning correctly, or were not scaled correctly. While meter comparisons were important for this blind study, these comparisons will be less important in future deployments of this technology. Meter data does not impact the recommendations of ECM directly, as ECM recommendations are not based on meter data being available. If meter data is available it increases the transparency of the energy performance of a building and can supplement the ECM decision process in support of the REM ECM recommendations.

There are numerous concerns with the quality of meter data at DoD buildings, including common issues of zero readings, time gaps, negative readings, large jumps or jumps in usage, and unknown or incorrect scaling of meters. There were also other issues where facility personnel were unaware of how meters were divided amongst building(s), how to access interval data, how to identify or correct meter scaling, and instances where staff inaccurately designated units, or the meter data was not trusted by staff familiar with the building (see Appendix D for summary of meter data issues with individual buildings).

The most common issues included:

- Zero readings (very common)
- Lack of interval data
- Negative readings (meter resets very common)
- Multiple meters on a building, but installation staff unaware of how the usage is divided
- Make-up readings (23rd hour of the day usually)
- Time gaps (power outages, etc.)
- Large usage/EUI spikes and or drops (could be legitimate or indicative of meter issues)
- Duplicate timestamps
- Unknown scaling
- Mislabeled units
- Difficulty obtaining 12 consecutive months of data
- Building meter data not trusted by POCs

A cluster of 12 buildings with data anomalies were removed from analysis due to:

- Meter scaling issues (4 buildings)
- Occupancy related issues (2 buildings)
- Lack of natural gas data that had been identified as available (3 buildings)
- Use of district steam instead of natural gas (3 buildings)

These numerous issues draw attention to the need for DoD to review data from existing meters for anomalies, and for additional and perhaps periodic personnel training as the Advanced Metering Initiative (AMI) continues throughout DoD installations.

Future research using the existing data set should compare current results to meter data after smoothing or removing outlier data.

8.2 SITE SELECTION AND DATA GATHERING

In general, installation personnel seem stressed, and found it difficult to take time to obtain metering data and answer building-related questions.

Several installations known to have individually metered buildings chose not to participate in REM project due to lack of manpower or previous commitments. The government sequester in effect during the study period may be adding to these resource and bandwidth issues.

Surveys to installation points of contact contained numerous energy-related questions that were used to help researchers interpret results, but are not necessary data inputs for the Rapid Energy Modeling workflows. Examples include questions about presence of data centers, number of personnel, the number of computers and servers, and the presence of kitchen or laboratory equipment, etc. Additional questions inquired about any LEED or Energy Star certifications and interior usage percentages in order to identify buildings that were mixed-use. While not factored into the building models this information helped provide context around results. When technology transfer occurs and scales across installations, data requirements can be limited to model inputs – and when unknown, defaults can be used simplifying the process.

In some cases, suspected misinformation was provided in the survey responses, particularly in estimates for window to wall ratios. When these values were unknown or suspected to be incorrect, values were estimated from onsite or aerial images. Software defaults of 40% for window to wall ratio were not used, as this high value is not representative of DoD buildings, which tend to have much lower window to wall ratios than modern commercial buildings.

Another area of uncertainty for some installations was related to existing HVAC systems. Researchers initially asked for general descriptions of HVAC systems but received minimal information with which to make appropriate HVAC system selections in the modeling tools. The initial approach was modified and facility staff was then asked to identify the most appropriate HVAC system from a list. This approach helped pinpoint the best matched HVAC system in the software tools.

Data requirements for the model can be streamlined to the following minimum data requirements:

- **Location and confirmation that building is visible via Google satellite**
- **Building year of construction and major renovation**
- **Building Use Type**
- **Operating Schedule**
- **Gross Floor Area**
- **Building Height** *(whether/not height includes unconditioned attic space or open air, conditioned spaces?)*
- HVAC system type or selection of best fit from Vasari or GBS selection options
- Number of floors *(can be estimated from satellite if unavailable)*
- Floor to floor height *(can be estimated from satellite if unavailable)*
- Percentage window glazing *(can be estimated from satellite/aerial images if unavailable)*
- Percentage skylight glazing *(can be estimated from satellite if unavailable*)
- Exterior wall construction & insulation levels *(can be estimated from satellite/aerial images and year of construction /renovation if unavailable)*
- Roof construction & insulation levels *(can be estimated from satellite and year of construction /renovation if unavailable)*
- Glazing type & skylight types: single pane, dual pane, triple pane; tinted, low-e *(can be estimated based on year of construction /renovation and location if unknown)*
- Documentation of known structural or operational idiosyncrasies

When some model inputs are unknown, assumptions can be made based on year of construction and/or retrofit and satellite images from Google or Bing. It is recommended that users try both Google and Bing, as the two sites often differ dramatically in the level of detail and quality of images provided.

If a user wants to minimize assumptions about a building, they either need knowledge of the building or access to construction documents. Construction documents would also provide the most accurate information on building floor area; however it is understood that accessing and then interpreting these construction documents could take considerable time, depending on the expertise of the user, and the availability of the documents. The use of as-built documentation was initially explored as a method for data capture; this information can be used to define interior zoning, space use types, mechanical/ electrical system design and building envelope design but given the time required, it is better suited to creation of detailed energy models, not rapid energy models.

While many assumptions can be derived from satellite images and on-site visits are not required for the REM workflows, it is helpful to have knowledge of the building, access to building documentation or access to someone with knowledge of the building to help determine model inputs.

8.3 ANALYTICAL MODELING

The analysis platform and workflow do not allow for capturing unregulated/process loads. Types of spaces with high energy consumption have potential to throw off results. Examples may include: labs, data centers or kitchens. And process load types such as exterior lights, elevators, lab equipment, or machine room equipment may also have an effect on end use.

It should also be noted that this REM methodology using the DOE 2.2 engine is not capable of modeling district systems such as steam or chilled water, nor is it capable of modeling multiple HVAC systems, radiant heat, or heat recovery systems.

Sensitivity in the models is derived from limitations in modeling or understanding of the spaces such as attics, basements, atriums, unconditioned spaces, and double height spaces. There may also be impact from exterior obstructions such as overhangs, adjacent buildings and solar shading. There may be impact from roof zones fabric gains and users need to know whether or not they are conditioned areas and treated as part of the overall floor area. Understanding of the operational schedule is also important also useful is an understanding of seasonal variations or periods or non-use, which happens frequently for DoD dormitories.

The building models that most closely followed the building profiles were also the closest in replicating the metered energy use, and it is possible that a better understanding of operating schedules, seasonal variations in usage and of space use diversity could have improved results.

Green Building Studio Development

The recently added Potential Energy Savings (PES) feature within the REM software (Green Building Studio) allows multiple simultaneous energy simulation runs, each varying values for building features. This offers significant benefit in that it automates initial exploration and identification of ECMs, allowing users to quickly see which building parameters have the most influence on energy consumption and the highest opportunity for potential energy savings.

The current ESTCP project used a beta version of the PES tool which ran 50 different building simulations. The production version since released utilizes 37 parameters and tests extreme values against the baseline mode in the initial model. This format can provide teams with a high level understanding of PES the building energy performance to each measured parameter and can provide a great deal of insight on building sensitivity to various parameters of the buildings performance.

Green Building Studio has the capability of analyzing renewable energy potential, including photovoltaic and wind energy and can also calibrate results to specific weather years for which meter data is available. A government satellite blackout in the fall of 2012 prevented researchers from calibrating energy models to the weather year in GBS and manual calibration using external weather data files was outside of the scope of the project. Future research should explore calibration to actual weather for a specific year and document which buildings would be best for renewable energy implementation based on assumed installation costs, available utility rates, modeled geometry and location.

9.0 FUTURE OF RAPID ENERGY MODELING

Rapid Energy Modeling has the potential to help DoD scale energy assessments across the building portfolio, determine which buildings in the portfolio present the best opportunity for retrofits, quickly evaluate relative benefits of energy conservation measures through auto-simulation of potential energy savings, and contribute to energy and cost savings for the DoD.

Future technical studies of REM may prove useful, for instance examining connections to operational asset management and real property databases systems such as U.S. Army Corps of Engineers Builder software, the Military Health Service Defense Medical Logistics Standard Support System (DMLSS) or the Air Force Geo-base system. With these systems; operational, material and geometric attributes of the model may be effectively loaded without operator input, scripting the data loading phase could scale the process exceptionally. With integration to these systems the REM process could prove more efficient by working within the context of the daily activities of the installation and would allow for REM analysis on the entire installation at once (Figure 53). This would allow installations to have EISA type reporting information for the entire energy modeled installation inventory each year, as opposed to 25% annually in currently mandates.

Figure 53-Peterson Air Force Base Concept - Installation Wide Energy Model

Deeper investigations may include applying REM across more climates zones and building types, comparisons of results based on building size and climate zone, or examinations of results when comparing with meter data at intervals vs. no interval data. Studies on the potential improved accuracy of REM when using smoothed meter data, as well as tracking the actual energy savings of simulated ECMs to the actual installed energy conservation hardware over time are all productive areas of future evaluations for this REM technology.

The REM technology appears to be culturally acceptable, it is low cost and allows a much larger population of DoD staff (with less expertise) to gain an understanding of the energy performance of their portion of the DoD building portfolio. These attributes make production deployment and further technical evaluations both good candidates for future actions with REM.

10.0 REFERENCES

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Appendix A: Points of Contact

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone E-mail	Role in Project
John Sullivan	Autodesk; Autodesk, Inc. 111 McInnis Parkway San Rafael, CA 94903	john.sullivan@autodesk.com; 301-529-7165	PI
Jennifer Rupnow	Autodesk	jennifer.rupnow@autodesk.com; 831-295-3444	Co-PI
Vincent Corsello	Autodesk	vincent.corsello@autodesk.com; 312 502 2249	Co-PI
John Rittling	Autodesk	john.rittling@autodesk.com; 703-827-7213	Collaborator
Mark Frost	Autodesk	mark.frost@autodesk.com; 541 399-2986	Collaborator
Aniruddha Deodhar	Autodesk	aniruddha.deodhar@autodesk.com; 415-356-3242	Collaborator
John Kennedy	Autodesk	john.kennedy@autodesk.com; 415-507-4739	Collaborator
Trish Shurtz	Autodesk	trish.shurtz@autodesk.com; 415-5131029	Collaborator
David Scheer	Autodesk	david.scheer@autodesk.com; 415-513-1935	Collaborator
Carlos Orona	Autodesk	carlos.orona@autodesk.com; 415-675-8205	Collaborator
Alan Jackson	CASE, Inc.; 401 Broadway Suite 1600 New York, NY 10013	a.jackson@case-inc.com; 212-255-5483	Collaborator
Steve Sanderson	CASE, Inc.	s.sanderson@case-inc.com; 212-255-5483	Collaborator
Annette Stumpf	ERDC-CERL; P. O. Box 9005, Champaign, IL 61826-9005	Annette.L.Stumpf@usace.army.mil; 217-373-4492	Collaborator
Dale Herron	ERDC-CERL	Dale.L.Herron@usace.army.mil; 800-872-2375	Collaborator
Julie Webster	ERDC-CERL	Julie.L.Webster@usace.army.mil; 800-872-2375	Collaborator
Richard Schneider	ERDC-CERL	Richard.L.Schneider@usace.army.mil; 800-872-2375	Collaborator
Louise Sabol	DCS; 11 Dupont Cir NW Washington, D.C., DC 20036	lsabol@dcstrategies.net; 202-222-0610	Collaborator
Barbara Heller	DCS	bheller@dcstrategies.net; 202-222-0610	Collaborator
Kesari Mudhagouni	DCS	kmudhagouni@dcstrategies.net; 202-222-0610	Collaborator
Gil Lurdes	Earle Naval Weapons Station Colts Neck NJ 732-866-2319	lurdes.gil@navy.mil; 732-866-2319	Installation POC
Allen Simpson	Fort Leonard Wood; | 1334 First Street-Bldg 2222 | Fort Leonard Wood, MO 65473-8944	allen.w.simpson2.civ@mail.mil; 573-596-0956	Installation POC
Jeannie Elseman	Fort Leonard Wood	jeannie.m.elseman.civ@mail.mil	Installation POC
Brian Parker	Fort Leonard Wood	bryan.l.parker.civ@mail.mil; 573-596-0901	Installation POC
Peter Behrens	Naval Station Great	peter.behrens@navy.mil; 847-688-2121	Installation POC

	Lakes; 2601 Paul Jones St, Great Lakes, IL 60088	ext 28	
Brian Eckert	Naval Station Great Lakes	brian.eckert@navy.mil; 847-204-2752	Installation POC
Sakhawat Amin	JBLM; Public works Joint Base Lewis McChord, WA 98433-9500	sakhawat.amin.ctr@mail.mil; 253-966-9011	Installation POC
Dave Krohn	JBLM; Public works Joint Base Lewis McChord, WA 98433-9500	david.a.krohn.civ@mail.mil; 253-966-1853	Installation POC
Evelyn Baskin	Panama City; NAVFAC SE, PWD Panama City 101 Vernon Ave, Bldg 126 Panama City, FL 32407	evelyn.baskin@navy.mil; 850-230-7176	Installation POC
Randy Pieper	Peterson AFB; 21st CES/CENP Peterson AFB, CO	randall.pieper.ctr@us.af.mil; 719-556-9590	Installation POC
Brian Ballweg	Port Hueneme; Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) Building 1100 1100 23rd Ave Port Hueneme, CA 93043	brian.ballweg@navy.mil; 805-982-1250	Installation POC
Roberto Valdez	Port Hueneme; Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) Building 1100 1100 23rd Ave Port Hueneme, CA 93043	roberto.valdes@navy.mil; 805-982-1704	Installation POC
Lance Mahar	Portsmouth; Building 59/2 Portsmouth Naval Shipyard, PWD Maine	lance.mahar@navy.mil; 207-438-5980	Installation POC
Elias Schtakleff	Seymour Johnson AFB; 1510 Wright Brothers Ave Goldsboro, NC 27531	Elias.Schtakleff@seymourjohnson.af.mil; 919-868-9179	Installation POC
Matthew Latham	Seymour Johnson AFB; 1510 Wright Brothers Ave Goldsboro, NC 27531	Matthew.Latham@seymourjohnson.af.mil; 919-722-7443	Installation POC

Appendix B: Summary Data- All Viable Buildings: Offices, Barracks, Specialty Use, Combined

Building Number	Building Type - Modeled	Division	Gross Floor Area- Modeled Conditioned Space	State	kWh From Meter	kWh from Model (GBS)	Mean Bias Error-Model Vs Meter - Electric	Accuracy Model Vs Meter - Absolute (Elec)	MMBTU From Meter	MMBTU From Model (GBS)	Mean Bias Error- Model Vs Meter - Gas	Accuracy Model Vs Meter Absolute (Gas)	Total Metered EUI (kBtu/SF)	Total Modeled EUI (kBtu/SF)	Mean Bias Error- Modeled Vs Metered - EUI (kBtu/SF)	Accuracy Model Vs Meter - Absolute (EUI)
B1	Office	Air Force	281,732	CO	5,590,418	4,593,182	-17.84%	82.16%	5524	1270.54	-77.00%	23.00%	87.33	60.15	-31.12%	68.88%
350	Office	Air Force	148,801	CO	1,728,137	2,046,233	18.41%	81.59%	2873.363	1611.969	-43.90%	56.10%	58.95	57.77	-2.00%	98.00%
1100	Office	Navy	120,925	CA	1,105,292	1,479,161	33.83%	66.17%	179.1	212.5311	18.67%	81.33%	32.68	43.51	33.14%	66.86%
110	Office	Navy	119,050	FL	1,768,200	1,897,648	7.32%	92.68%	2122.8	443.871	-79.09%	20.91%	68.52	58.13	-15.17%	84.83%
470	Office	Army	101,565	MO	1,621,858	1,564,214	-3.55%	96.45%	2922.467	1060.139	-63.72%	36.28%	83.28	63.00	-24.35%	75.65%
3369	Office	Joint Base	59,578	WA	469,930	560,350	19.24%	80.76%	962.9	503.6395	-47.70%	52.30%	43.08	40.55	-5.87%	94.13%
Cerl1	Office	Army	52,739	IL	1,288,807	1,062,475	-17.56%	82.44%	4560.38	1820.617	-60.08%	39.92%	169.88	103.28	-39.20%	60.80%
Cerl2	Office	Army	48,301	IL	979,952	1,022,858	4.38%	95.62%	4200.35	2543.372	-39.45%	60.55%	156.21	124.93	-20.02%	79.98%
581	Office	Navy	40,287	FL	716,700	604,483	-15.66%	84.34%	786.1	238.2419	-69.69%	30.31%	80.23	57.12	-28.80%	71.20%
4421	Office	Air Force	37,088	NC	706,325	594,687	-15.81%	84.19%	842	259.2037	-69.22%	30.78%	87.70	61.71	-29.63%	70.37%
Cerl3	Office	Army	23,639	IL	282,577	279,563	-1.07%	98.93%	2040.17	606.9196	-70.25%	29.75%	127.10	66.04	-48.04%	51.96%
1345	Office - Bank	Air Force	7,772	CO	118,197	92,989	-21.33%	78.67%	135.53	131.0553	-3.30%	96.70%	69.34	57.70	-16.79%	83.21%
1485	Office - Bank	Air Force	4,834	CO	57,680	63,413	9.94%	90.06%	142.1	121.2382	-14.68%	85.32%	70.12	69.85	-0.38%	99.62%
							Average Accuracy	85.70%			Average Accuracy	49.48%			Average Accuracy	77.34%
Summary Data for Offices							Mean Absolute Percentage Error (MAPE)	14.30%			MAPE	50.52%			MAPE	22.66%
							STDEV	8.93%			STDEV	25.15%			STDEV	14.41%
							CoV	10.41			CoV	50.84			CoV	18.63
							MFE	2.01			MFE	18.81			MFE	21
							MAD	7.21			MAD	18.85			MAD	22
							MSE	70.28			MSE	684.38			MSE	913.06

Building Number	Building Type - Modeled	Division	Gross Floor Area-Modeled Conditioned Space	State	kWh From Meter	kWh from Model (GBS)	Mean Bias Error-Model Vs Meter - Electric	Accuracy Model Vs Meter - Absolute (Elec)	MMBTU From Meter	MMBTU From Model (GBS)	Mean Bias Error- Model Vs Meter - Gas	Accuracy Model Vs Meter Absolute (Gas)	Total Metered EUI (kBtu/SF)	Total Modeled EUI (kBtu/SF)	Mean Bias Error-Modeled Vs Metered - EUI (kBtu/SF)	Accuracy Model Vs Meter - Absolute (EUI)
831	Barracks	Army	40,840	MO	948,960	777,496	-18.07%	81.93%	4257.628	3593.201	-15.61%	84.39%	183.56	152.96	-16.67%	83.33%
937	Barracks	Army	55,724	MO	1,296,922	880,220	-32.13%	67.87%	4359.926	3680.78	-15.58%	84.42%	157.68	119.97	-23.92%	76.08%
484	Barracks	Navy	96,130	FL	2,513,700	2,693,241	7.14%	92.86%	2208.8	6162.982	~~179.02%~~	~~-79.02%~~	112.22	159.73	42.33%	57.67%
9136	Barracks	Joint Base	25,349	WA	255,349	310,415	21.56%	78.44%	2732.8	1669.32	-38.92%	61.08%	142.19	107.65	-24.29%	75.71%
373	Barracks	Navy	76,282	ME	858,400	1,329,284	54.86%	45.14%	4,621	6200.039	34.17%	65.83%	98.98	140.75	42.20%	57.80%
Summary Data for Barracks							Avg Accuracy	73.25%			Average w. outlier removed	73.93%			Avg Accuracy	70.12%
							MAPE	26.75%			MAPE	26.07%			MAPE	29.88%
							STDEV	18.07%			STDEV	12.25%			STDEV	11.71%
							CoV	24.67			CoV	189.12			CoV	16.69
							MFE	0.999			MFE	12.43			MFE	2.71
							MAD	14.94			MAD	22.78			MAD	38.42
							MSE	279.24			MSE	650.45			MSE	1510.58
3650	Cafeteria	Air Force	28,013	NC	805,718	636,028	-21.06%	78.94%	2669.9	2294.736	-14.05%	85.95%	193.47	159.41	-17.61%	82.39%
4103	School	Air Force	25,851	NC	650,258	470,667	-27.62%	72.38%	0	310.1262			85.85	74.14	-13.64%	86.36%
4601	Firestation	Air Force	43,187	NC	564,493	746,343	32.21%	67.79%	1,890	781.9529	-58.63%	41.37%	88.37	77.09	-12.77%	87.23%
4537	Automotive Facility	Air Force	38,700	NC	613,119	549,983	-10.30%	89.70%	2,203	1251.493	-43.19%	56.81%	111.00	80.84	-27.17%	72.83%
640	Gym	Army	20,889	MO	287,682	304,660	5.90%	94.10%	2652.367	2627.316	-0.94%	99.06%	173.98	175.55	0.91%	99.09%
Summary Data for Speciality Use Buildings							Avg Accuracy	80.58%			Avg Accuracy	70.80%			Avg Accuracy	85.58%
							MAPE	19.42%			MAPE	29.20%			MAPE	14.42%
							STDEV	11.18%			STDEV	26.39%			STDEV	9.47%
							CoV	13.87			CoV	37.28			CoV	11.06
							MFE	6.56			MFE	10.57			MFE	17.13
							MAD	13.42			MAD	15.37			MAD	17.76
							Electric				Gas				EUI	
Summary Data for All Analyzed Buildings							Avg Accuracy	81.88%			Avg Accuracy	58.20%			Avg Accuracy	77.56%
							MAPE	18.12%			MAPE	41.80%			MAPE	22.44%
							STDEV	12.31%			STDEV	24.05%			STDEV	13.48%
							CoV	15.03			CoV	43.38			CoV	17.38
							MFE	2.78			MFE	13.30			MFE	16.08
							MAD	10.24			MAD	19.75			MAD	24.92
							MSE	154.12			MSE	671.74			MSE	989.07

Appendix C. Buildings Excluded from Core Analyses

ISSUE	Building Number	Building Type - Modeled	Division	Gross Floor Area- Modeled Conditioned Space	State	kWh From Meter	kWh from Model (GBS)	Mean Bias Error-Model Vs Meter - Electric	Accuracy Model Vs Meter - Absolute (Elec)	MMBTU From Meter	MMBTU From Model (GBS)	Mean Bias Error- Model Vs Meter - Gas	Accuracy Model Vs Meter Absolute (Gas)	Total Metered EUI (kBtu/SF)	Total Modeled EUI (kBtu/SF)	Mean Bias Error- Modeled Vs Metered - EUI	Accuracy Model Vs Meter - Absolute (EUI)
District Steam and Occupancy	GL 800 Series	Barracks	Navy	366,116	Great Lakes, IL	4,171,440	9,303,226	123.02%	-23.02%		41,140			96.59	199.09	106.13%	-6.13%
District Steam	GL 7103	Barracks	Navy	528,130	Great Lakes, IL	7,884,549	8,953,476	13.56%	86.44%		50,717			74.94	153.89	105.34%	-5.34%
District Steam	GL 7230	Drill Hall (modeled as Convention Center)	Navy	64,816	Great Lakes, IL	760,680	1,071,961	40.92%	59.08%		3,588			206.22	111.80	45.79%	54.21%
Occupancy; No Gas Data	PH 1444	Office	Navy	66,855	Port Hueneme, CA	484,693	767,677	58.38%	41.62%		1219			24.74	57.42	132.08%	-32.08%
No Gas Data	PH 850	Office	Navy	15,859	Port Hueneme, CA	129,376	172,539	33.36%	66.64%		51.19315			27.84	40.36	44.96%	55.04%
Scaling	1236	Office	Joint Base	47,564	Tacoma Area WA	32,470	486,235	1397.49%	-1297.49%	864.5	1006.361	16.41%	83.59%	20.51	56.05	173.33%	-73.33%
Occupancy	11654	Barracks	Joint Base	82,338	Tacoma area, WA	346,502	978,256	182.32%	-82.32%	1559.71	5324.061	241.35%	-141.35%	33.31	105.21	215.89%	-115.89%
Occupancy	635	Barracks	Army	40,947	Fort Leonard Wood, MO	317,543	790,062	148.80%	-48.80%	3031.25	4605.068	51.92%	48.08%	100.50	178.32	77.44%	22.56%
Data Center	PH 2	Office (actually an IT Center)	Navy	49,424	Port Hueneme, CA	2,152,454	827,901	-61.54%	38.46%		158.6228			148.64	60.38	59.38%	40.62%
Scaling	C2	Office	Navy	19,065.75	Colts Neck, NJ	6,700.00	234,258.15	3396.39%	-3296.39%	1,018.92	459.09	-54.94%		54.64	66.01	20.81%	79.19%
Scaling	C50	Automotive Facility	Navy	26,380	Colts Neck, NJ	87,500	365,096	317.25%	-217.25%	2123.5	238.9984	-88.75%	11.25%	91.82	56.30	38.69%	61.31%
Scaling	C29	Cafeteria	Navy	19,208	Colts Neck, NJ	133,400	328,806	146.48%	-46.48%	3779.6	2168.674	-42.62%	57.38%	220.47	171.33	22.29%	77.71%

Appendix D: Issues Identified with Meter Data at Individual Buildings

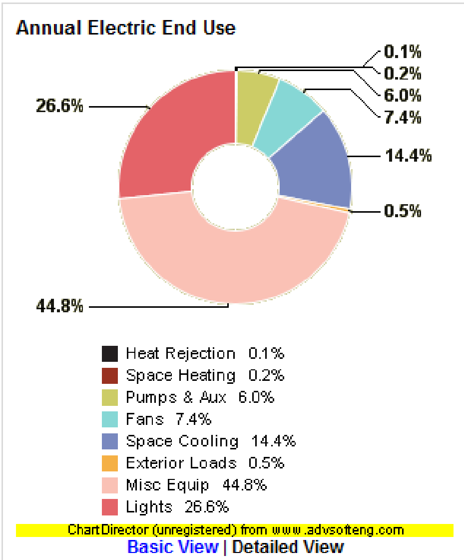
BASE	Building Number	ERDC-CERL Notes- Buildings in RED were removed from core analysis due to: inadequate data, inaccurate or questionable data, lack of natural gas data, or use of district systems
Peterson AFB Air	1	
	Bank 1- 1485	Zero gas use Jun-Aug confirmed
	Bank 2 - 1345	Zero gas use Jun-Aug confirmed
	2004	POC says data unreliable (remove) (did not model)
	350	
Panama City Navy	581	Summer hi/Spring lo elec (gas opposite)
	485	Sep 2012 elec peak; scaling issue with this building
	484	Fall hi/Spring lo elec; May FY10/Jul FY11 gas spikes
	110	Fall hi/Spring lo elec (gas opposite); May FY10 gas spike
Joint Base Lewis-McChord Air and Army	3369	odd electric trend
	1236	Summer/Winter hi; Spring/Fall lo; scaling issue
	9136	daily meter resets (use monthly); elec & gas trend together (no A/C)
	11654	odd electric trend; occupancy concerns
Port Hueneme, CA Navy	Bldg 2	Jan'12 elec dip; odd elec trend
	Bldg 850	very low elec reads w/o scaling; somewhat high elec reads w/ scaling; odd elec trend
	Bldg 1100	very low elec reads w/ & w/o scaling, perhaps due to LEED EB remodel
	Bldg 1444	very low elec reads w/ & w/o scaling; trending flat; no gas data
ERDC CERL Army	Building 1	drop in Nov elec use; gas data from one meter for all 3 buildings ; divided by building gross floor area
	Building 2	drop in Nov elec use; gas data from one meter for all 3 buildings ; divided by building gross floor area
	Building 3	flat elec trend; gas data from one meter for all 3 buildings ; divided by building gross floor area
Fort Leon. Wood Army	B635	metered 22 Jun 2012; using partial Jun'12 & Jun'13 elec data; Dec'12 & Apr'13 elec drops; occupancy concerns
	B831	Feb FY11 drop in elec; Apr FY10 drop in elec; Feb'13 gas dip
	B640	Jul'12 elec peak
	B470	2 elec meters; Apr'12 elec dip; Feb'13 gas dip; gas vol corrector lowered Mar'13 read; use trends for missing/altered data
	B937	Feb'13 gas dip
Seymore AFB - North Carolina Air	4601	slight uptick of gas Apr 2011
	4421	gas spike Apr 2011; gas drop Jun 2011
	3650	Jul 2012 elec peak
	4537	Jul 2012 elec peak
	4103	fully elec
Portsmouth Naval Shipyard (Maine) - Navy	373	No FY10 elec to match FY10 gas (do not use); May FY11 elec lo; Jul FY12 gas drop

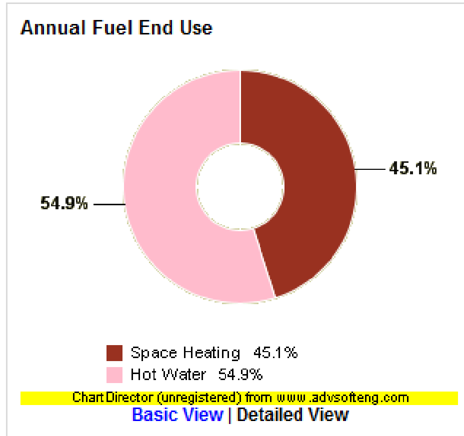
Naval Weapons Station Earle (New Jersey)	C29	Winter elec peak; Odd electrical data perhaps due to scaling; gas maybe ok

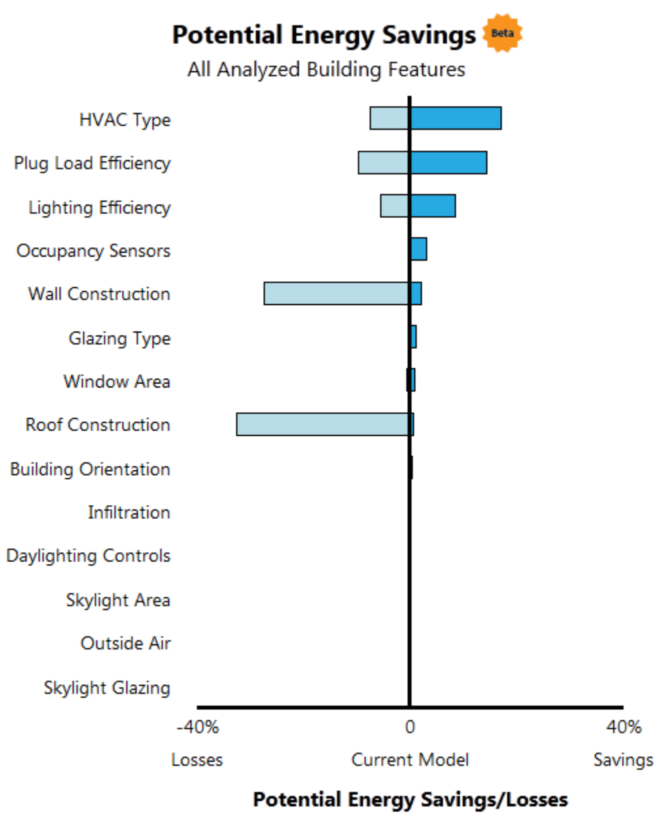
Navy	C50	Spring elec peak; Odd electrical data perhaps due to scaling; gas maybe ok
	C2	Spring elec peak; Odd electrical data perhaps due to scaling; gas maybe ok
NAVSTA Great Lakes Navy *(not clear how models will work-experimental)*	Building 1 - 7230	Nov/May lo elec reads annually (seasonal AHU/AC switchover?); steam (heat) reads have 2-yr pattern (odd). District Steam
	Building 2 - 7103/7104/ 7105	Jul-Sep/Nov-Dec hi/lo elec reads; flat gas trend (<kitchen only) (ignore sgl lrg spike & drop); Jan-Mar/Sep-Oct hi/lo steam reads; most '11-'12 steam data is errant or estimated
	Building 3 – 830, 831, 832, 835, 836, 838, 839	Jul/Dec hi/lo elec reads; Feb/Oct hi/lo steam reads; some negative steam data

Appendix E: Modeled End Use Breakdowns and Potential Energy Savings Charts

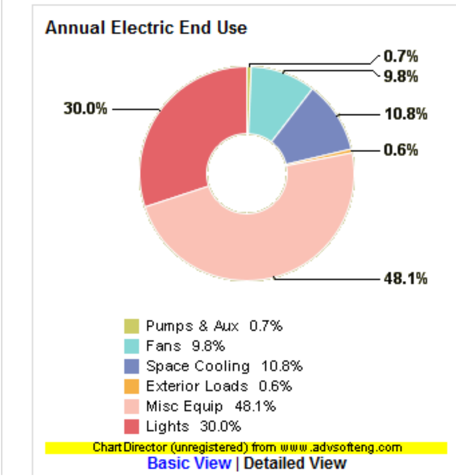
Peterson – Building 1 Modeled End Use Breakdowns and Potential Energy Savings Charts

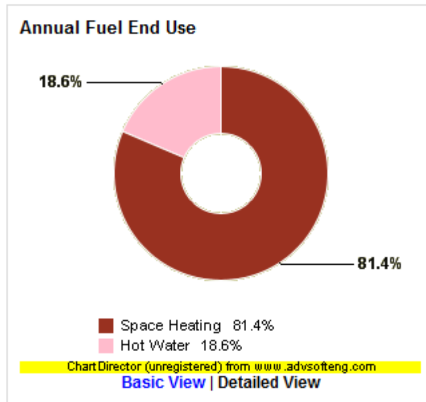


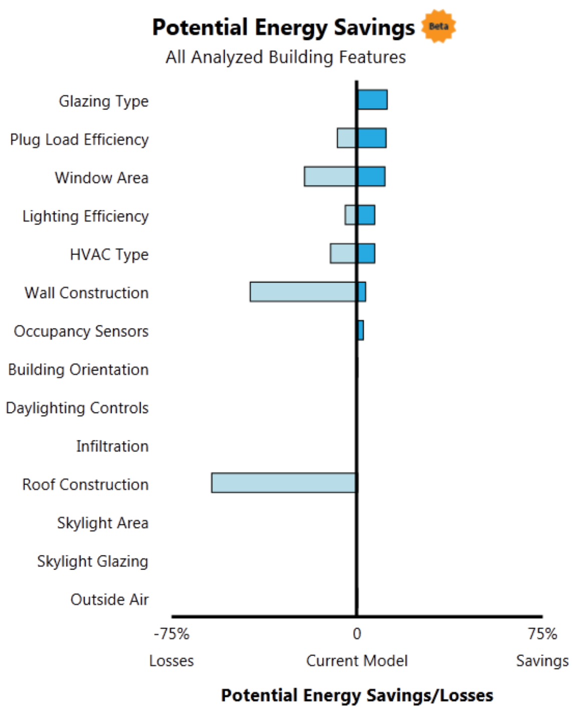




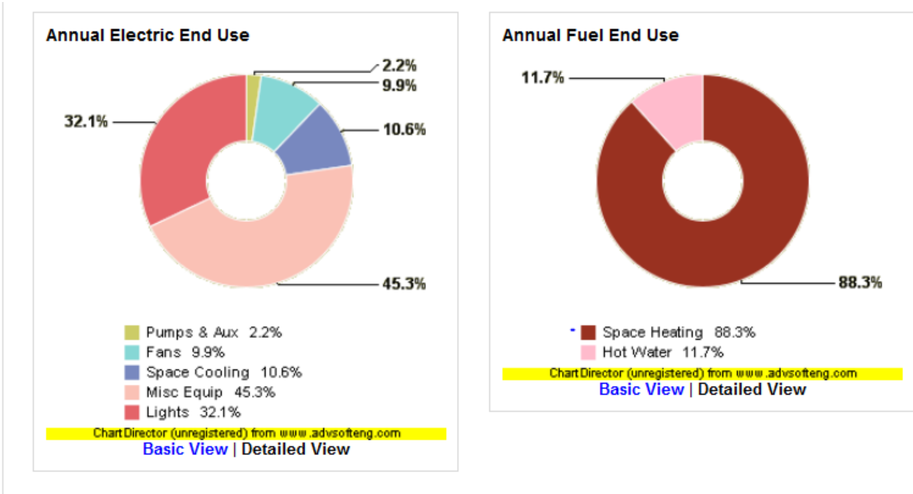
Peterson 350 Modeled End Use Breakdowns and Potential Energy Savings Charts

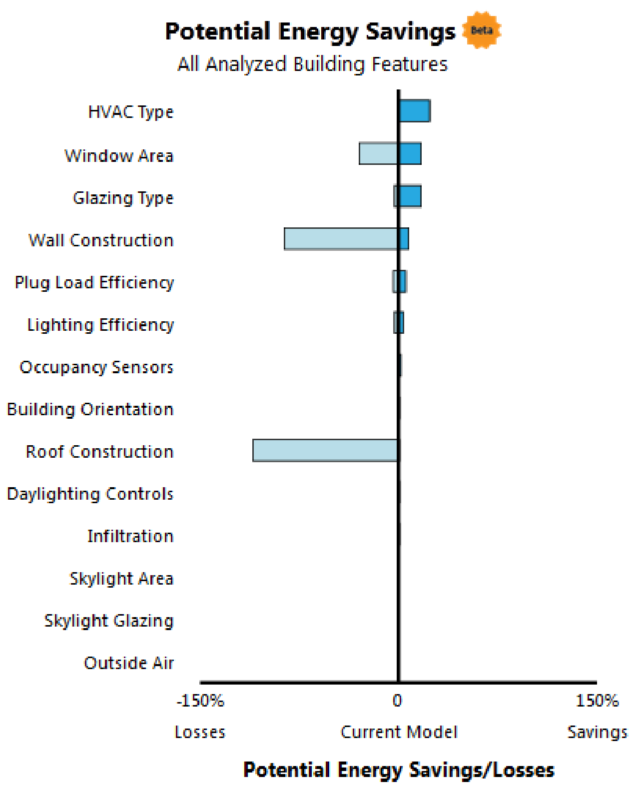




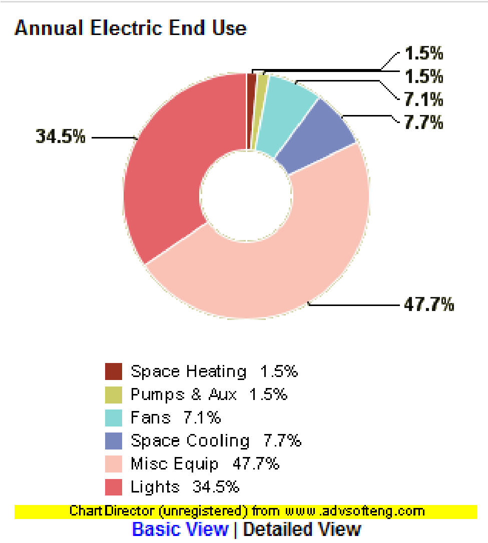


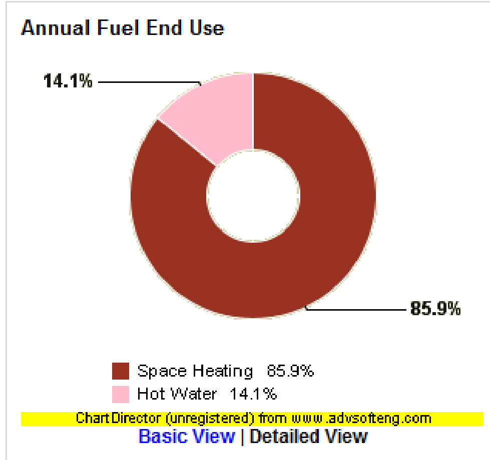
Peterson 1485 Modeled End Use Breakdowns and Potential Energy Savings Charts

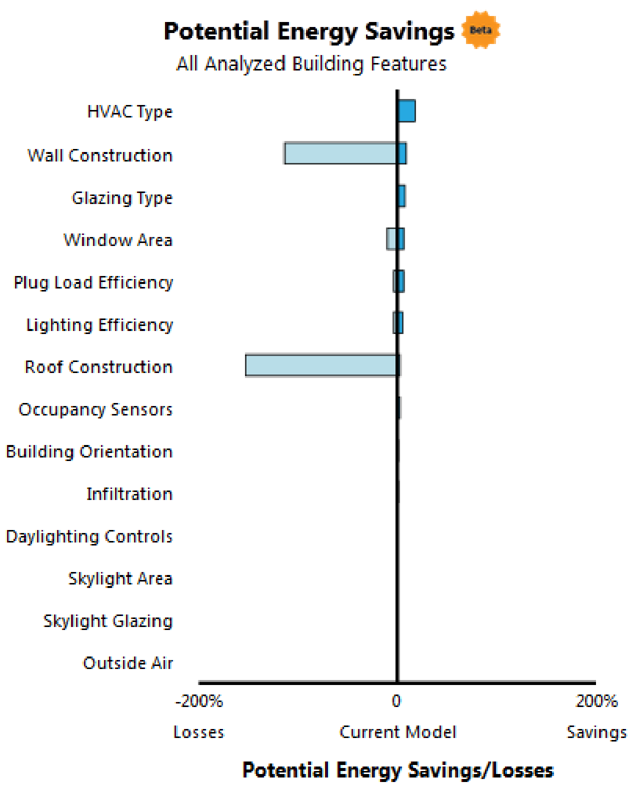




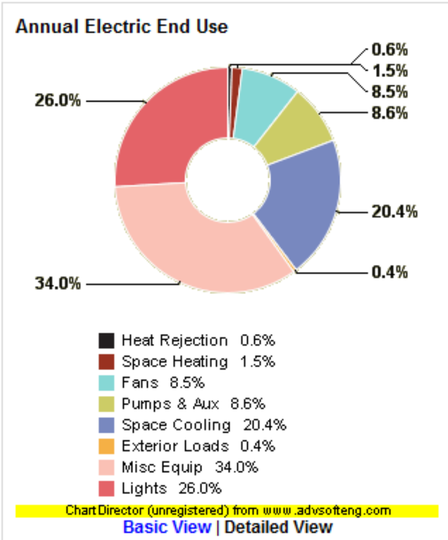
Peterson 1345 Modeled End Use Breakdowns and Potential Energy Savings Charts

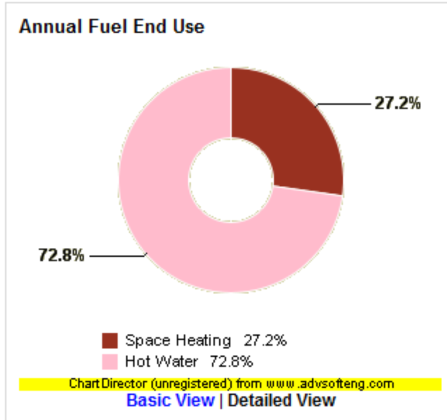


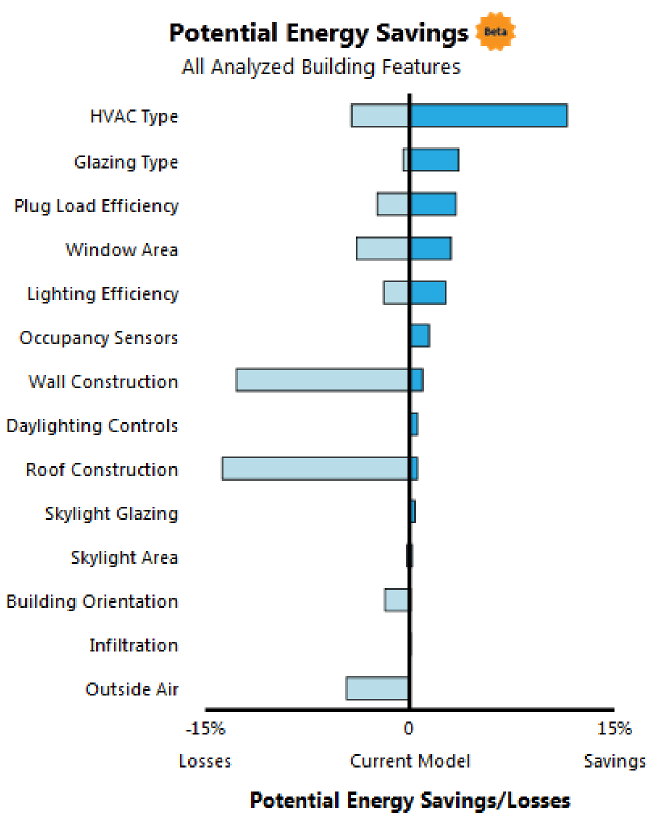




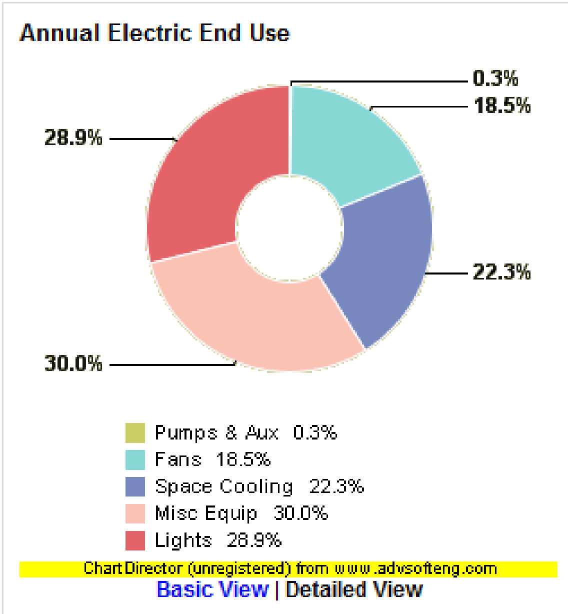
Fort Leonard Wood 831 Modeled End Use Breakdowns and Potential Energy Savings Charts

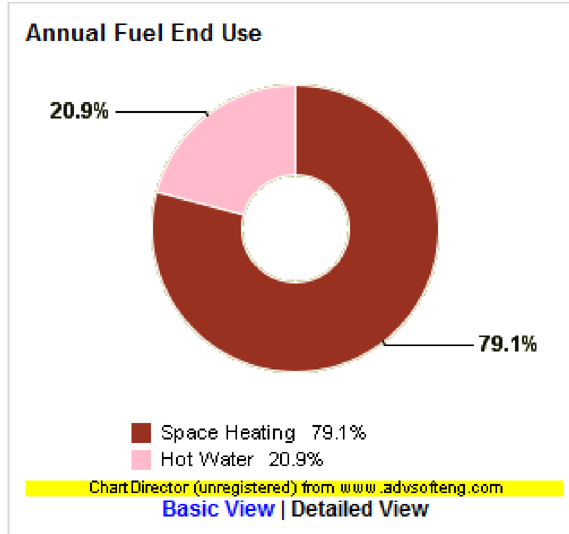


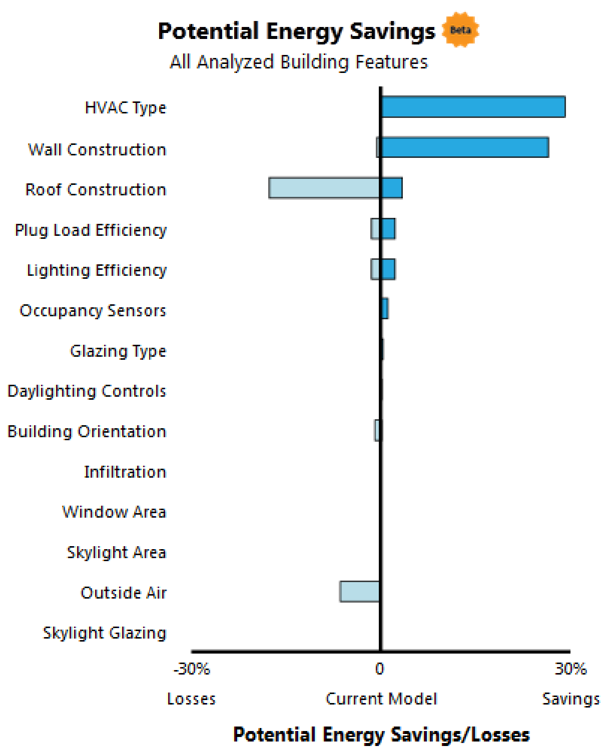




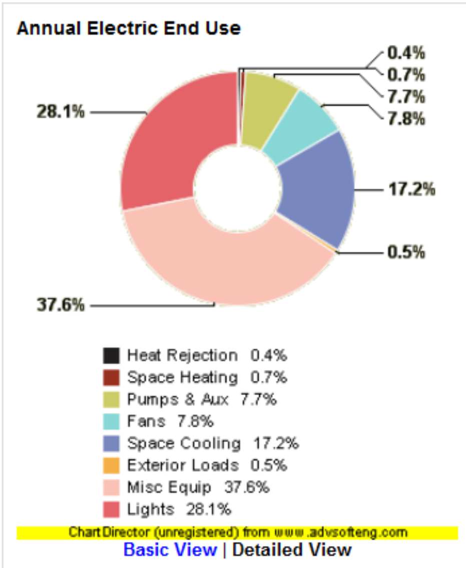
FLW 640 Modeled End Use Breakdowns and Potential Energy Savings Charts

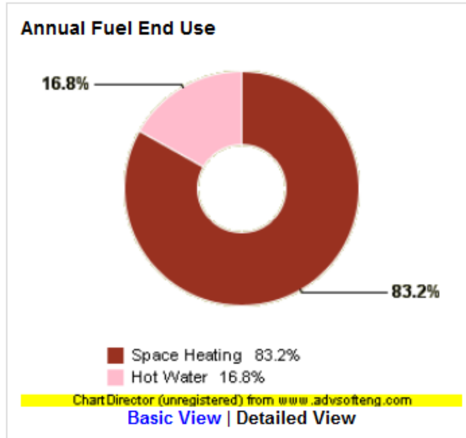


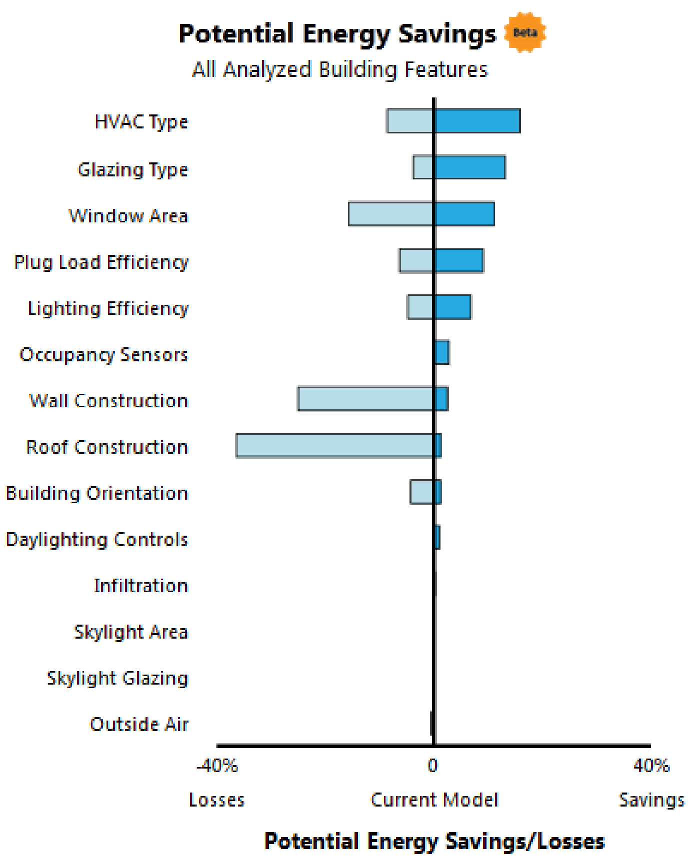




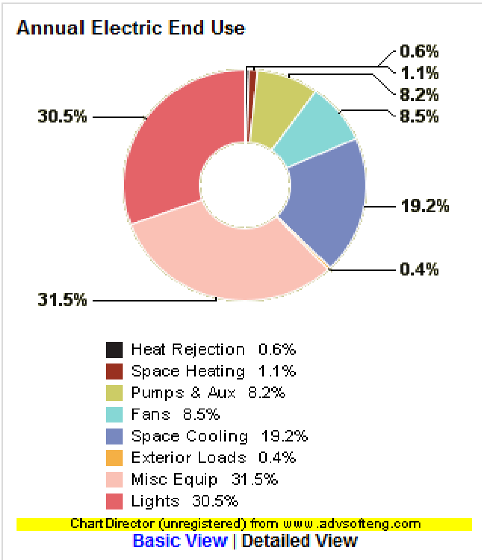
FLW Building 470 Modeled End Use Breakdowns and Potential Energy Savings Charts

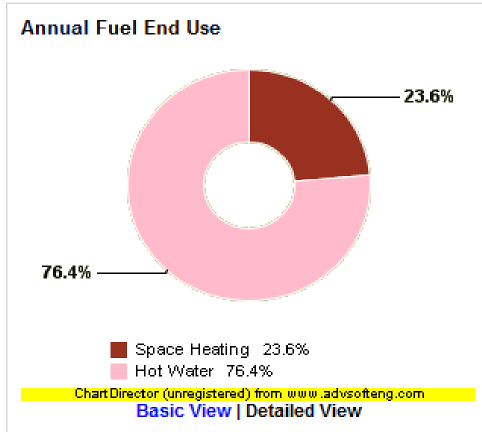


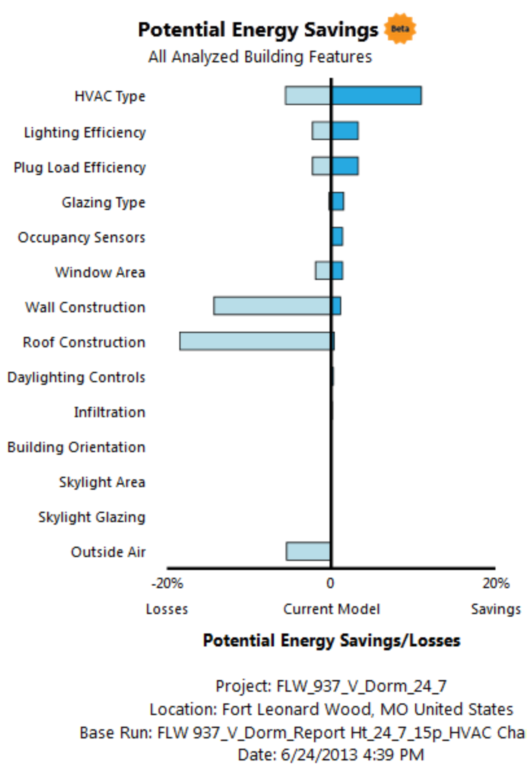




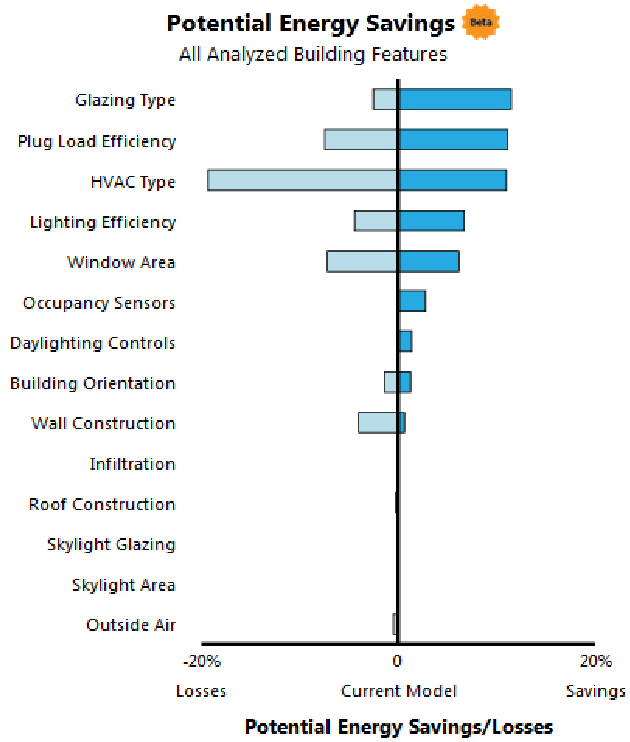
FLW 937 Modeled End Use Breakdowns and Potential Energy Savings Charts

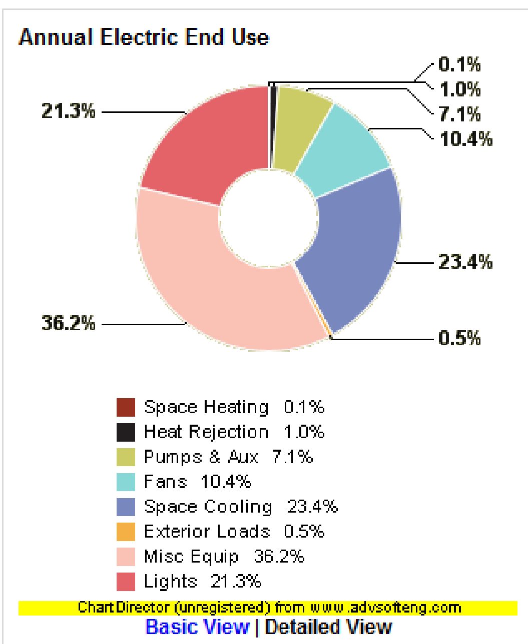


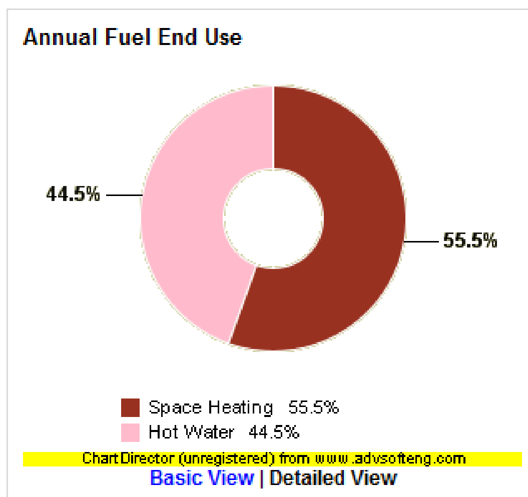




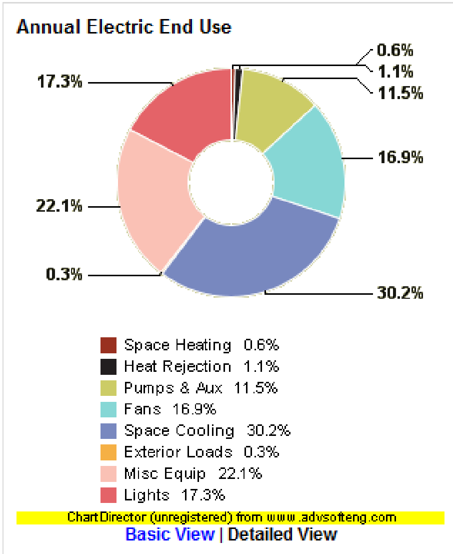
Panama City 110 -Modeled End Use Breakdowns and Potential Energy Savings Charts

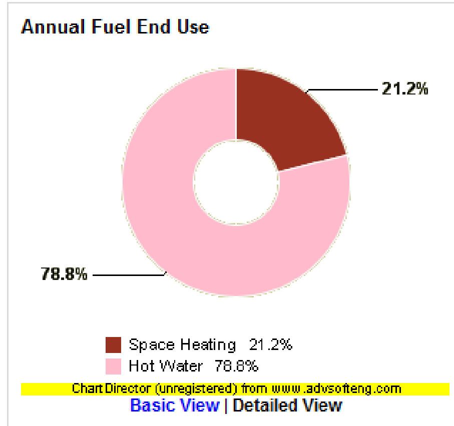


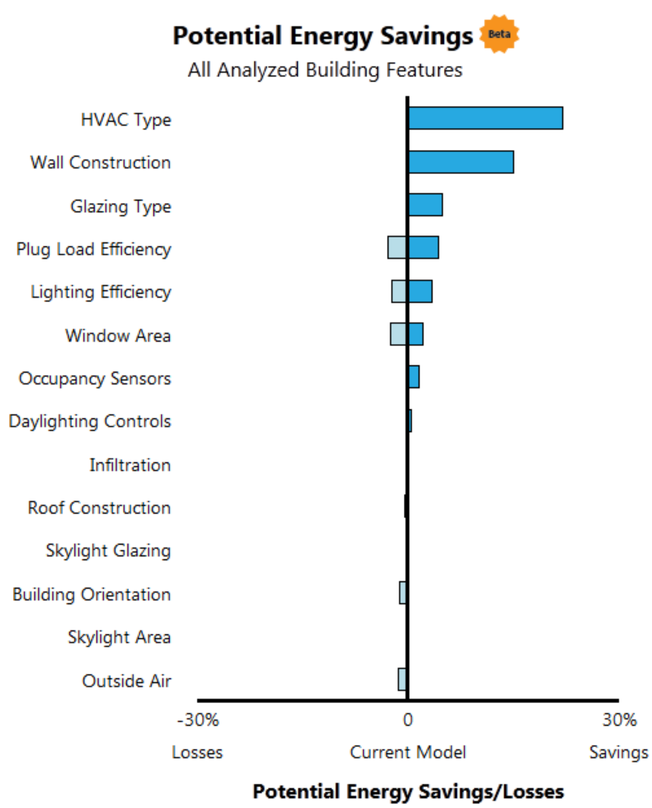




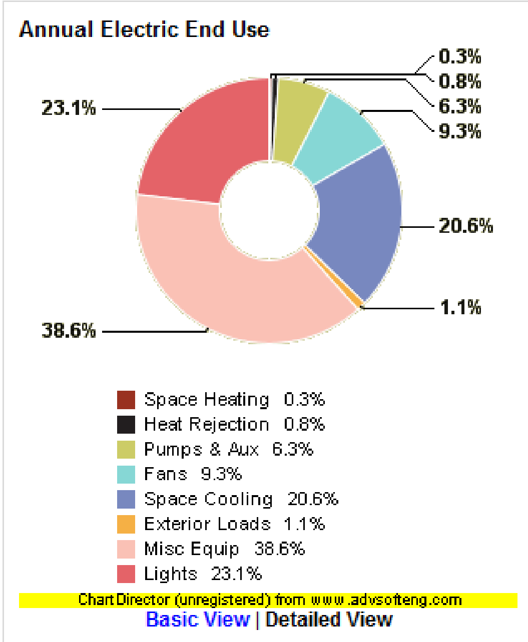
Panama City 484 -Modeled End Use Breakdowns and Potential Energy Savings Charts

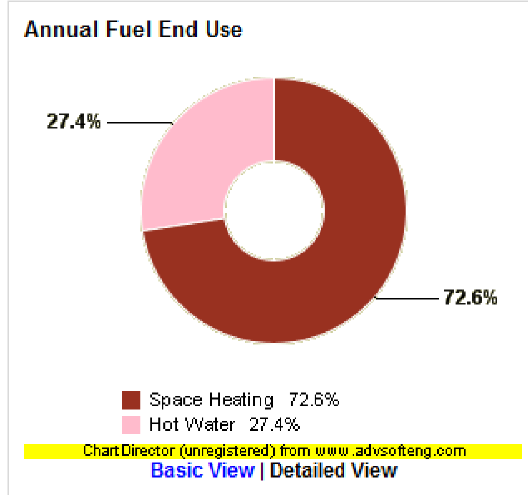


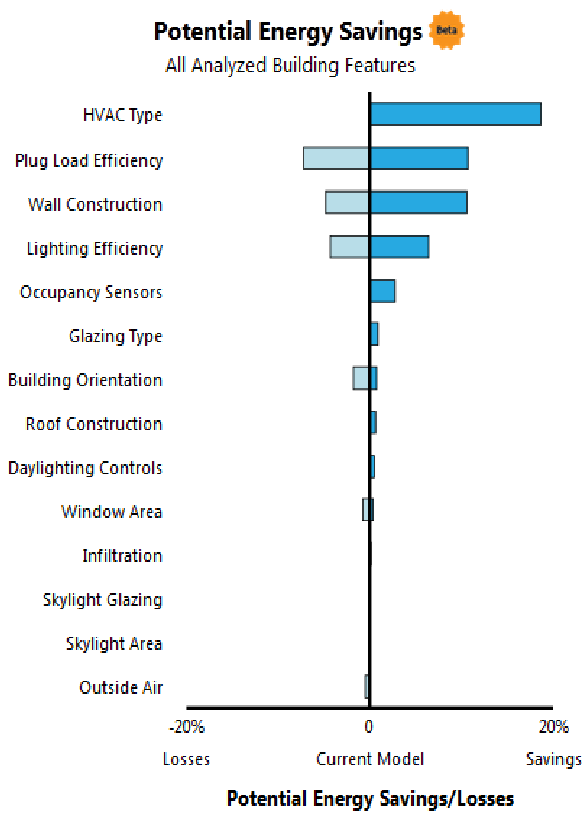




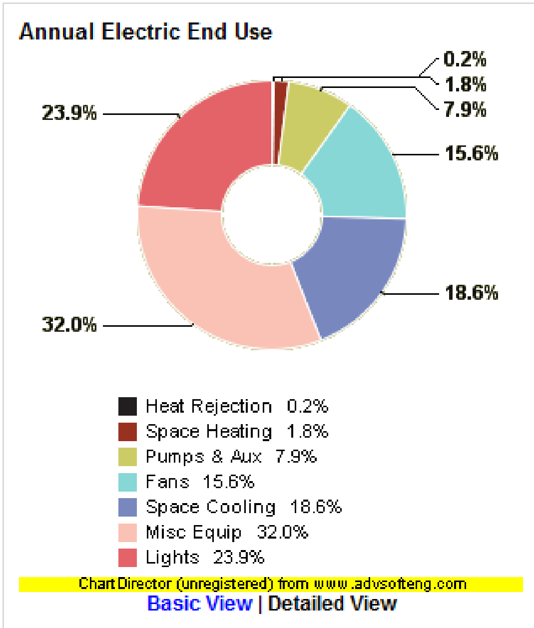
Panama City 581-Modeled End Use Breakdowns and Potential Energy Savings Charts

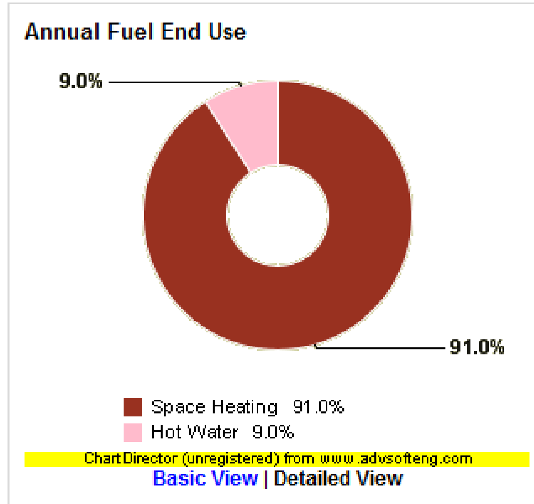


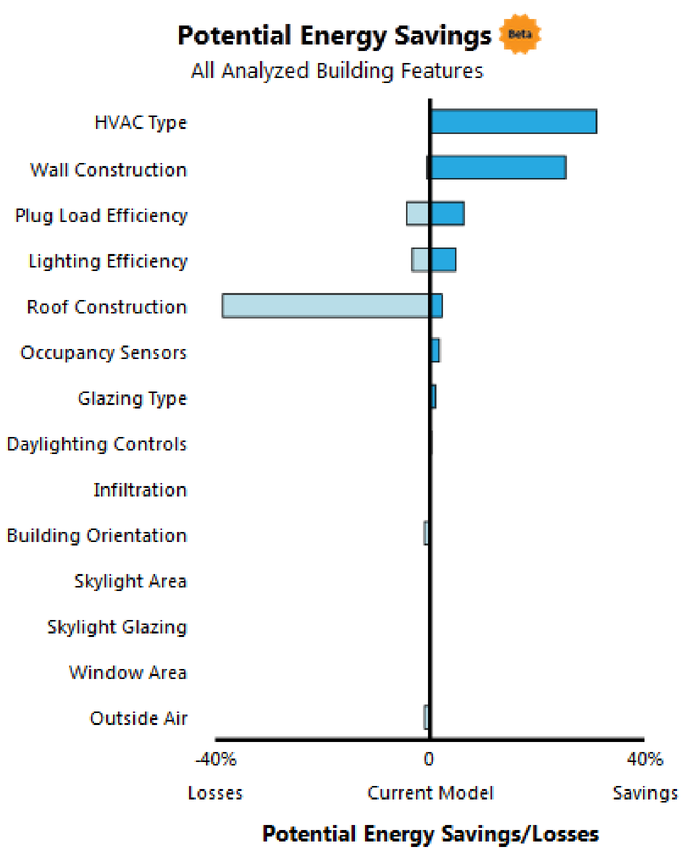




CERL Building 1-Modeled End Use Breakdowns and Potential Energy Savings Charts







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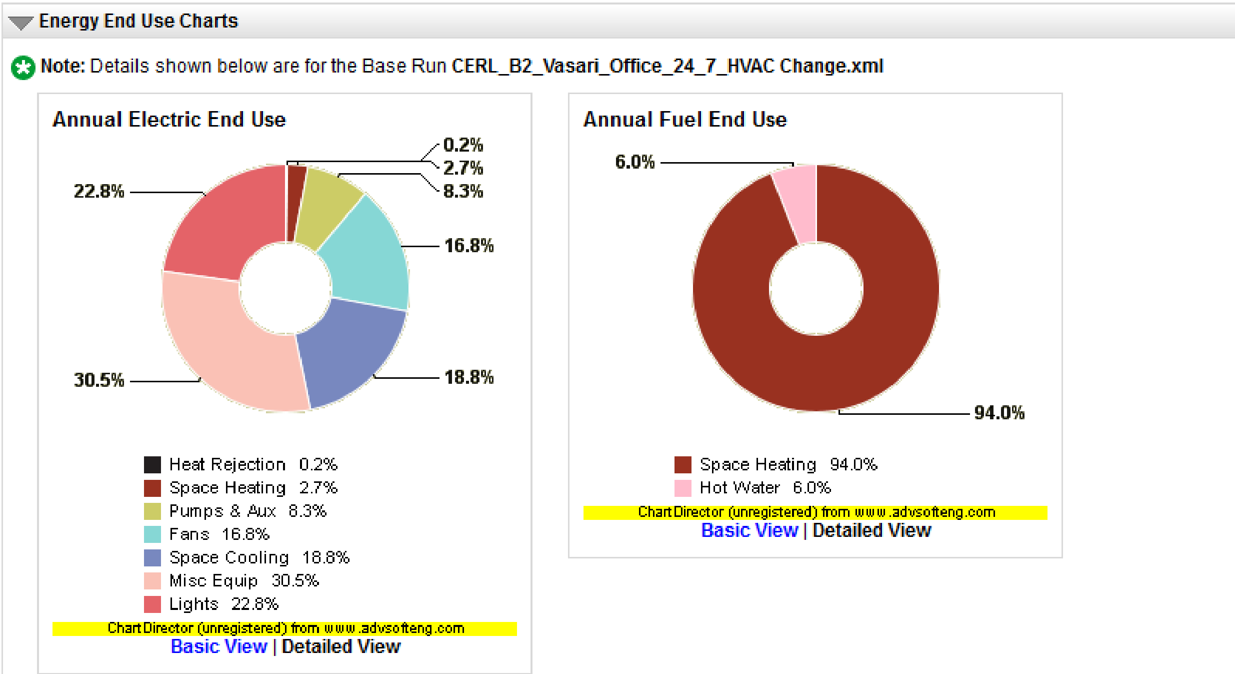
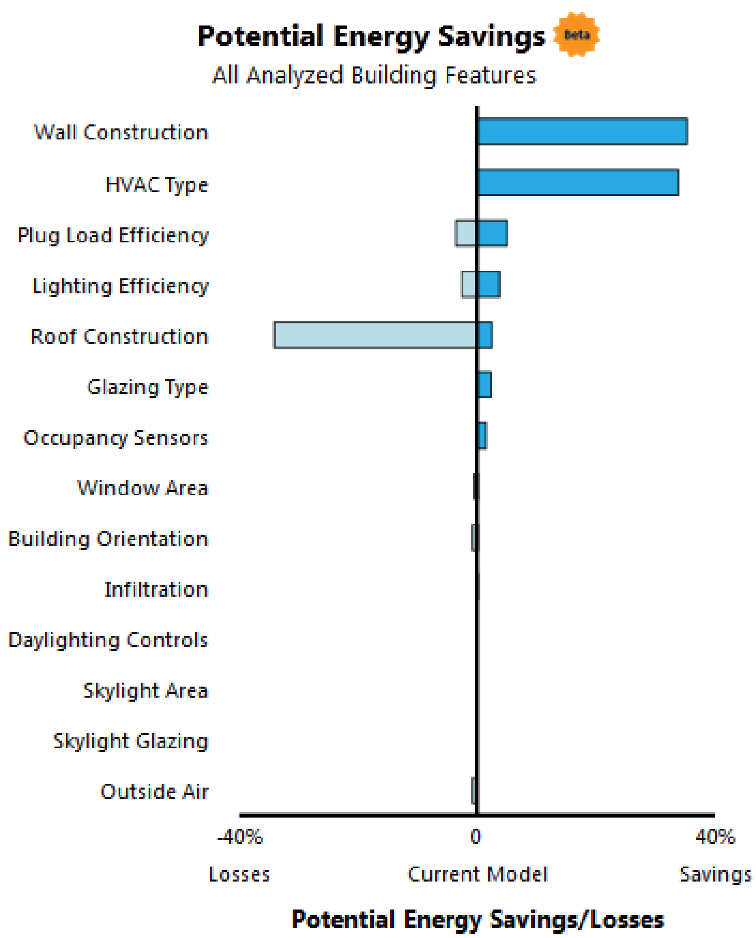
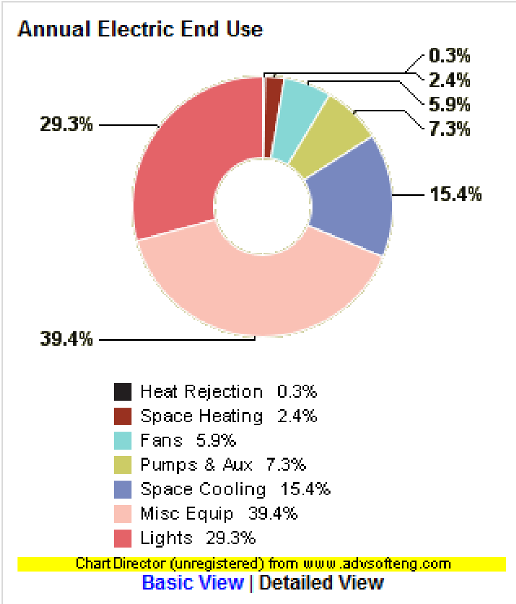
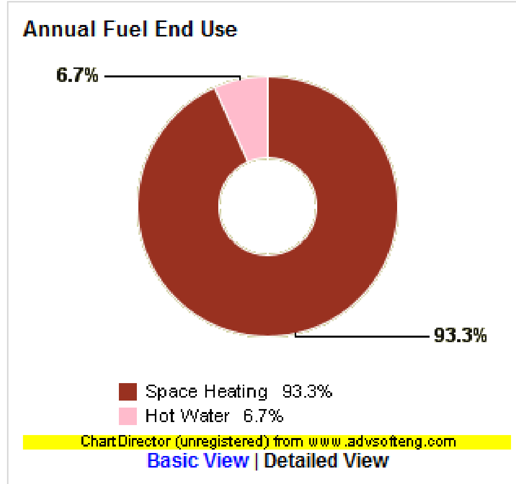
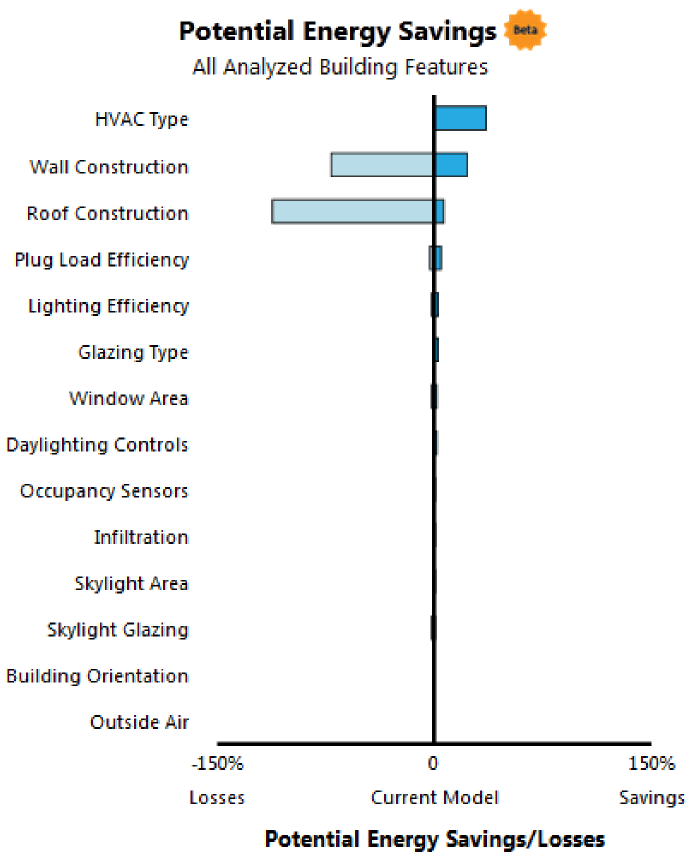




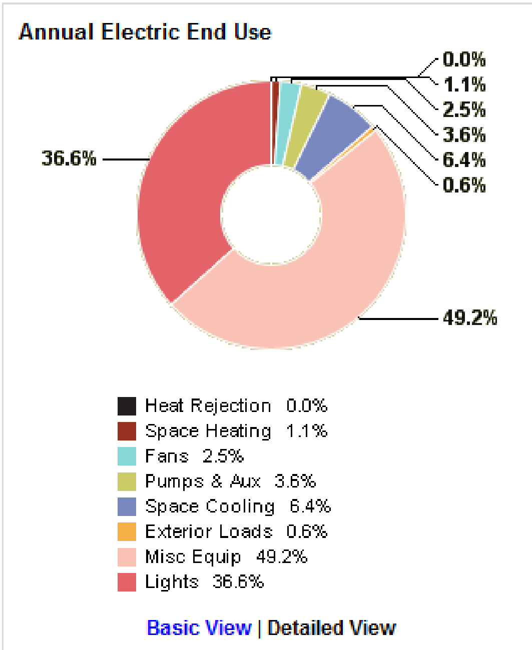
CERL Building 3-Modeled End Use Breakdowns and Potential Energy Savings Charts

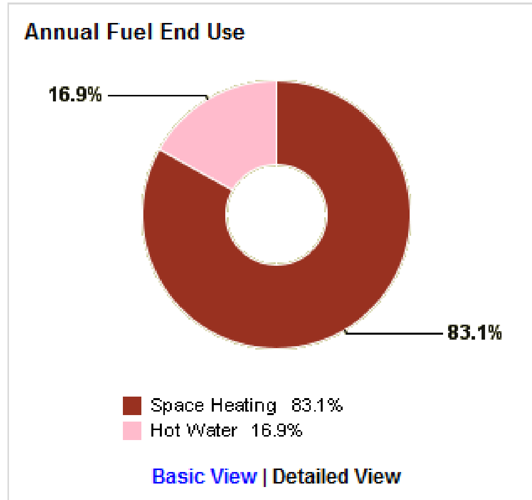


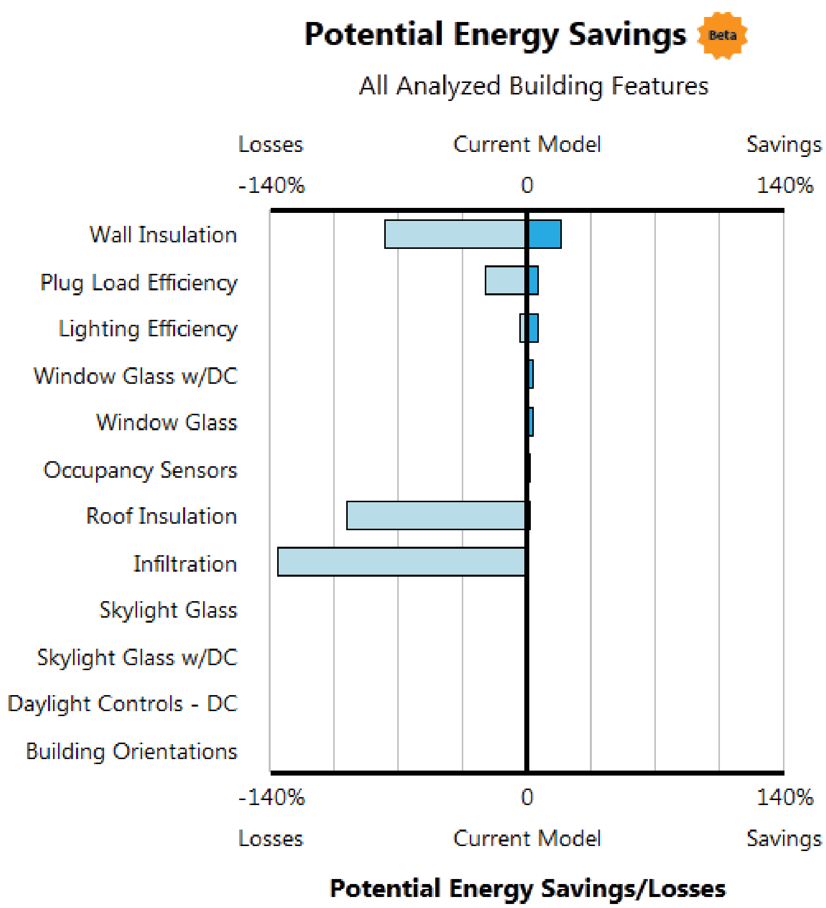




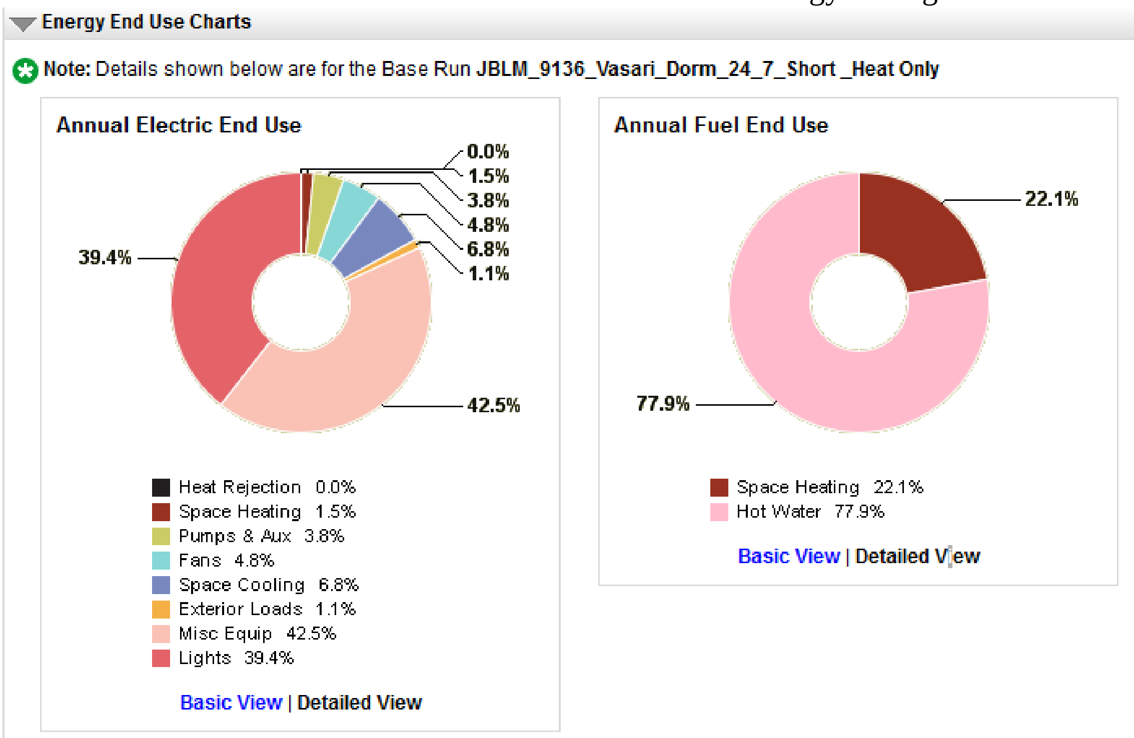
JBLM 3369-Modeled End Use Breakdowns and Potential Energy Savings Charts

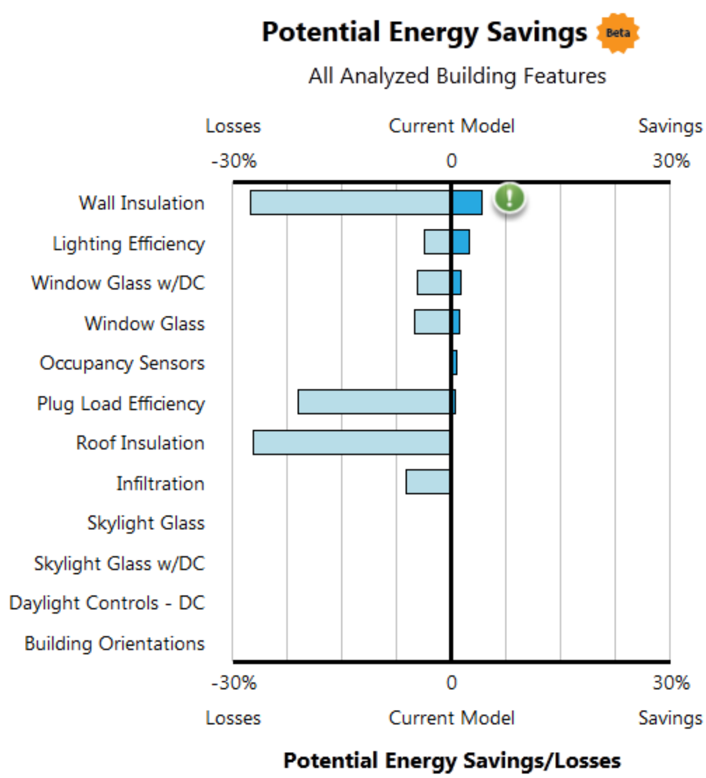




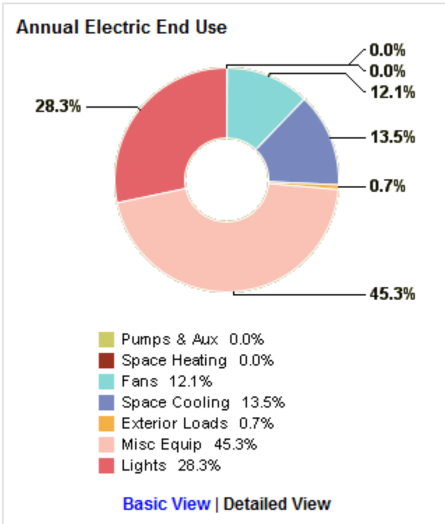


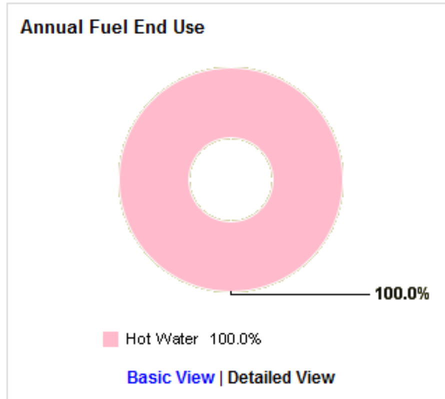
JBLM 9136-Modeled End Use Breakdowns and Potential Energy Savings Charts

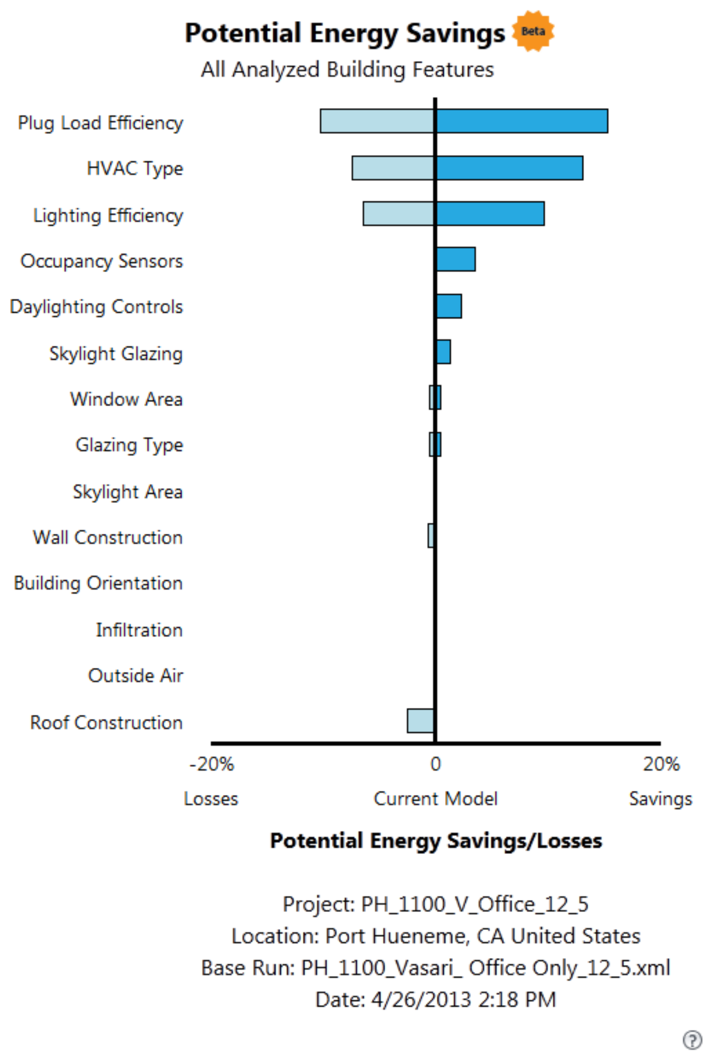




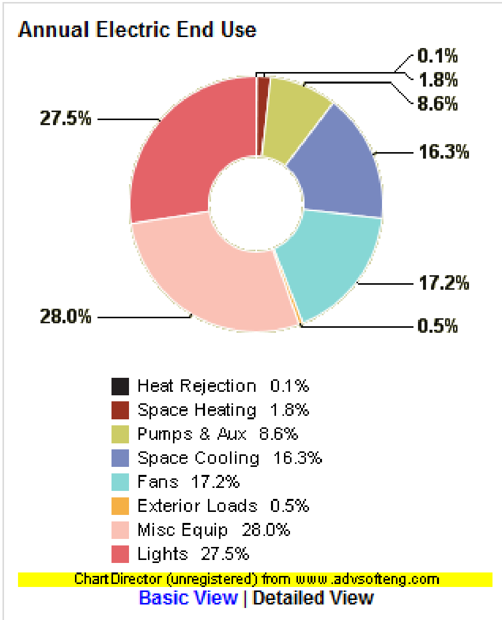
Port Hueneme 1100-Modeled End Use Breakdowns and Potential Energy Savings Charts

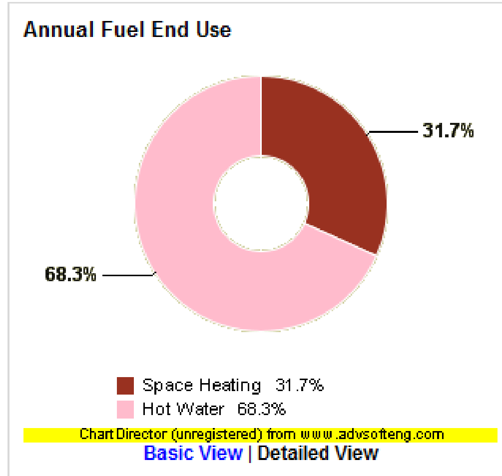


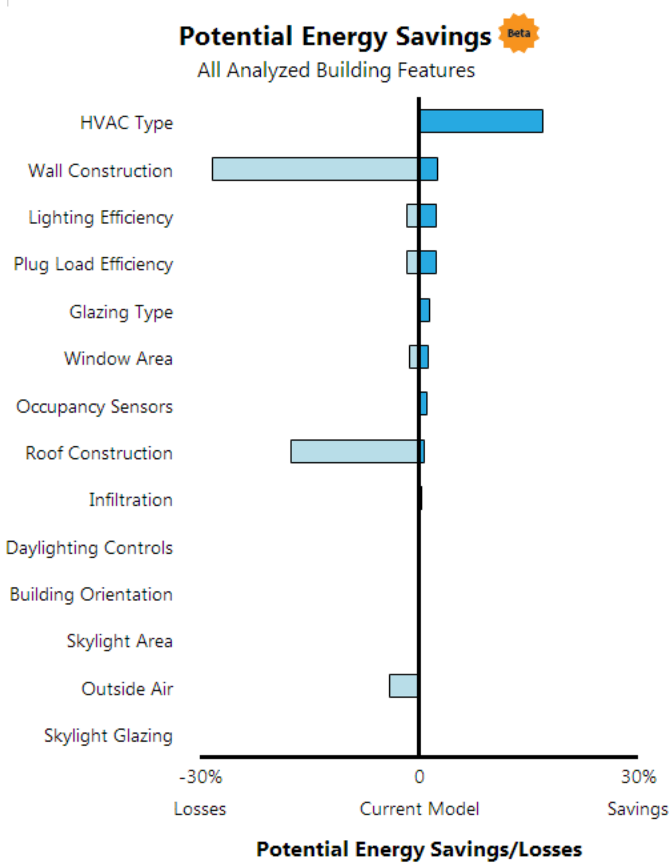




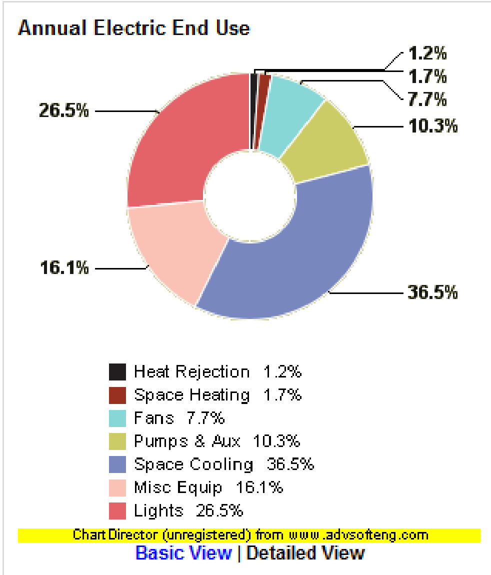
Portsmouth 373-Modeled End Use Breakdowns and Potential Energy Savings Charts

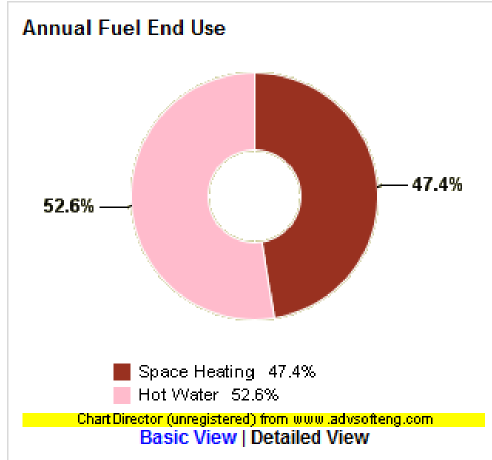


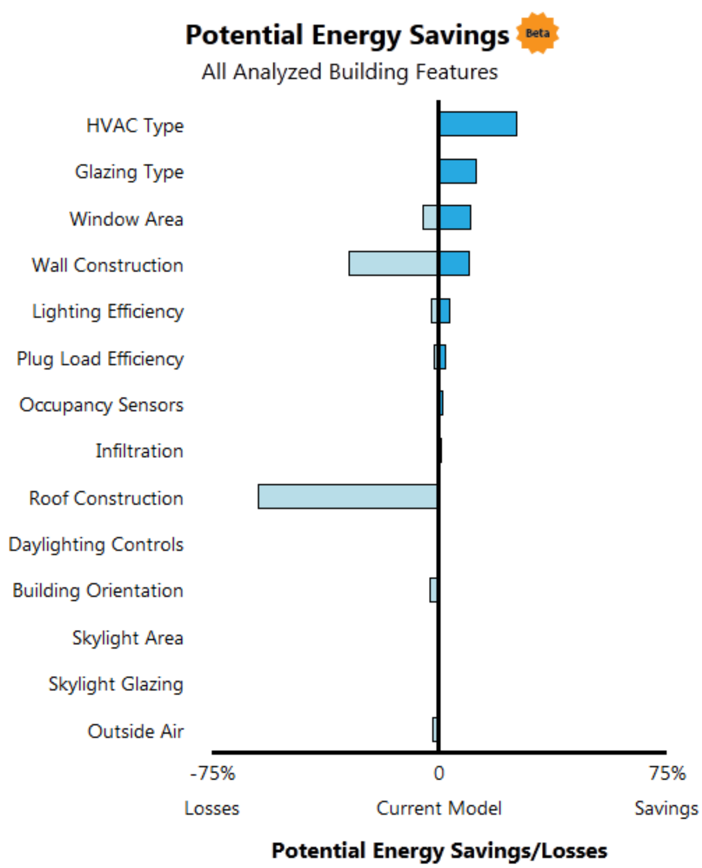




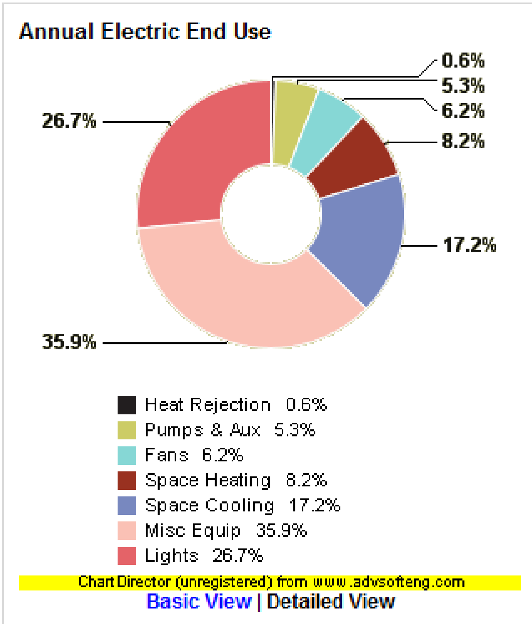
Seymour 3650-Modeled End Use Breakdowns and Potential Energy Savings Charts

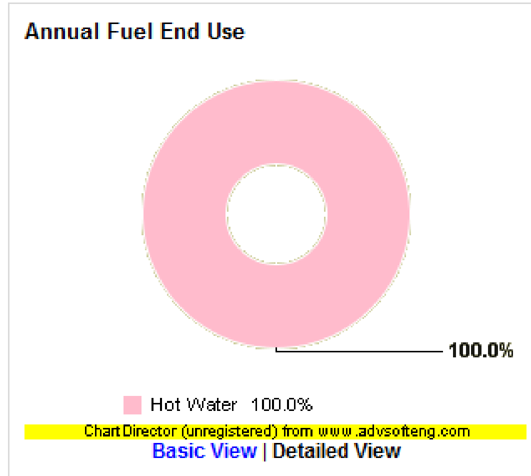


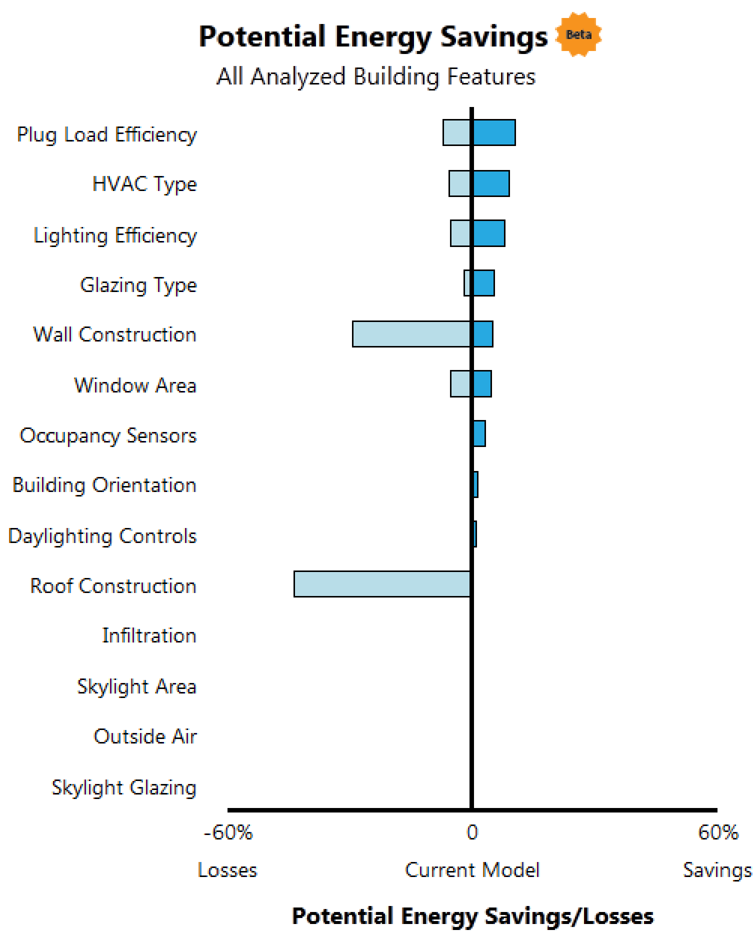




Seymour 4103-Modeled End Use Breakdowns and Potential Energy Savings Charts







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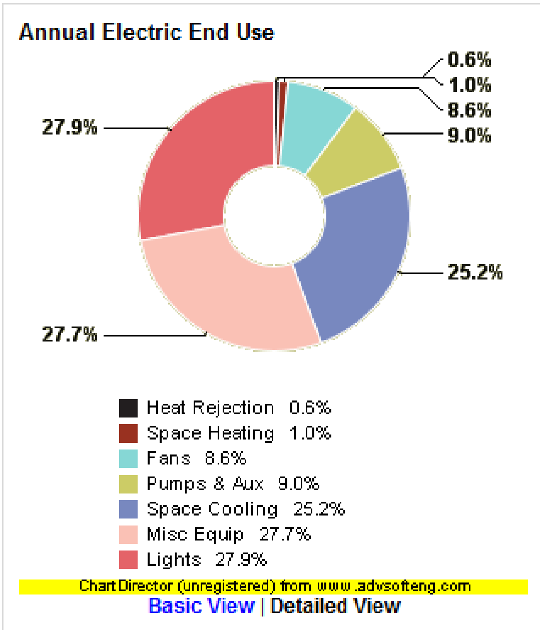
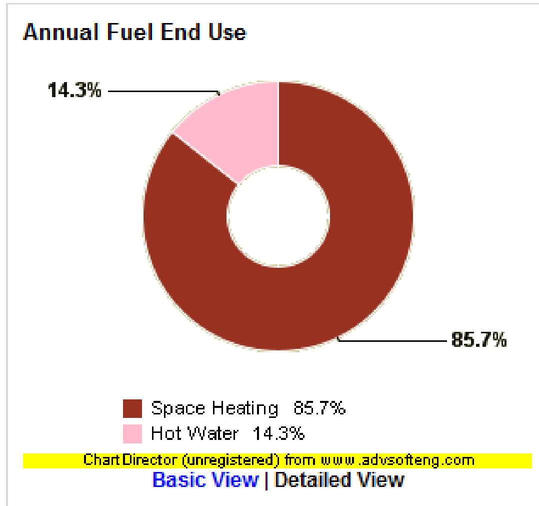
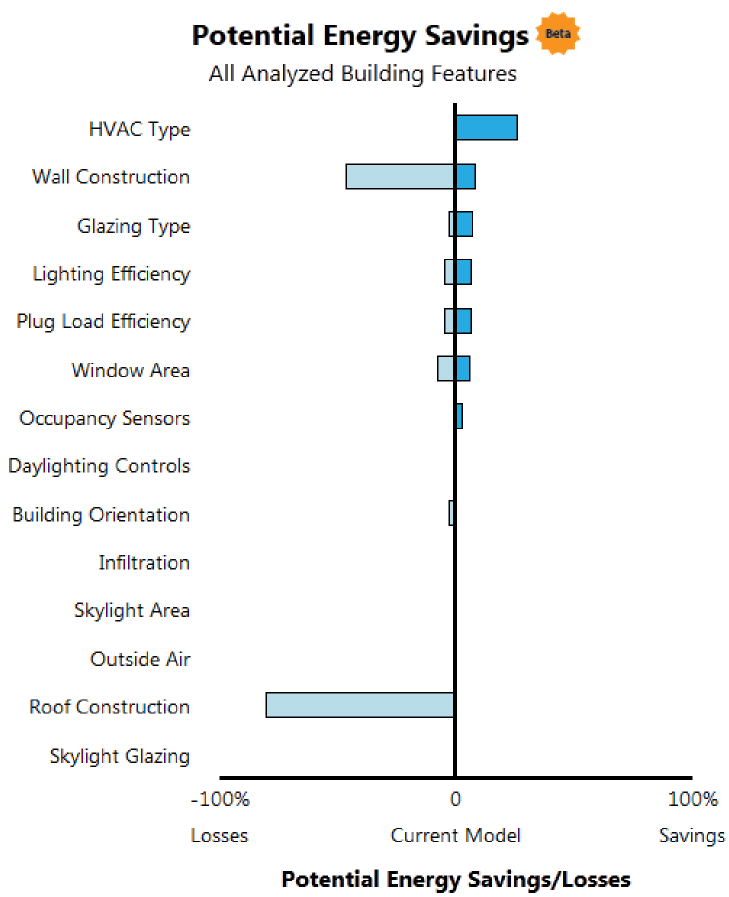
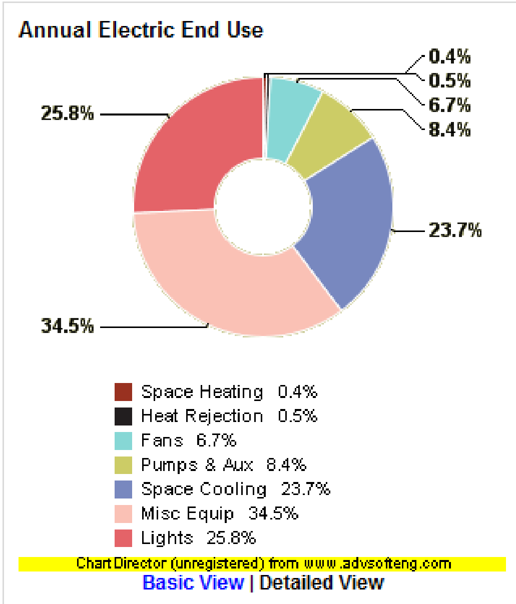
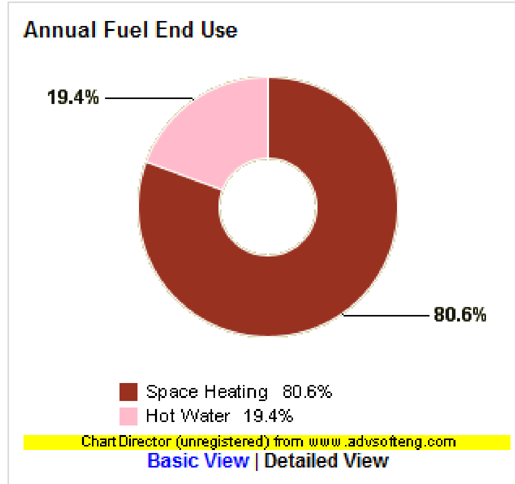


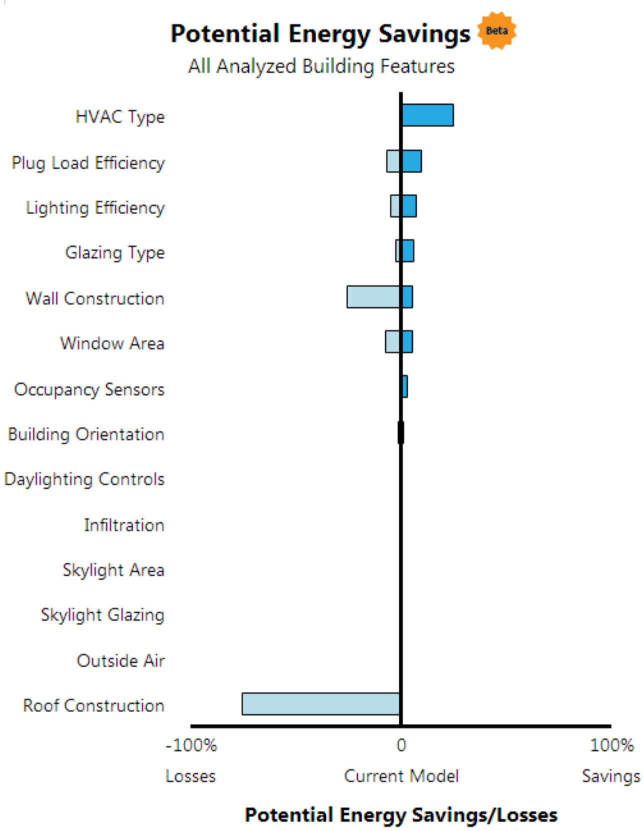




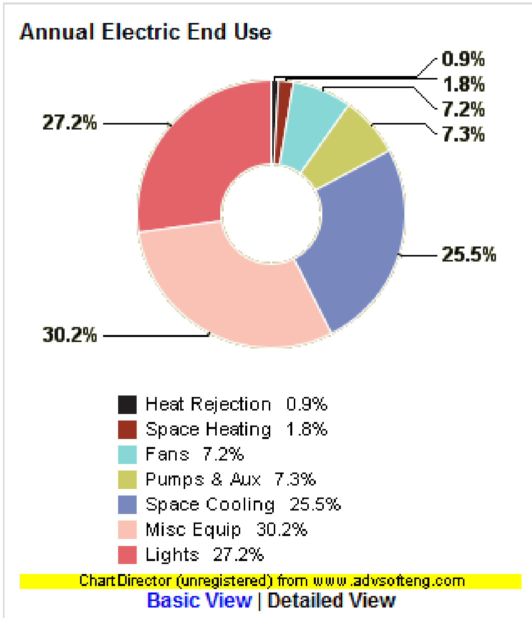
Building 4421-Modeled End Use Breakdowns and Potential Energy Savings Charts

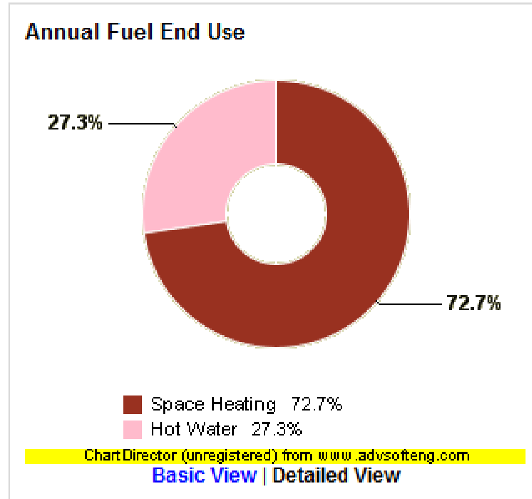


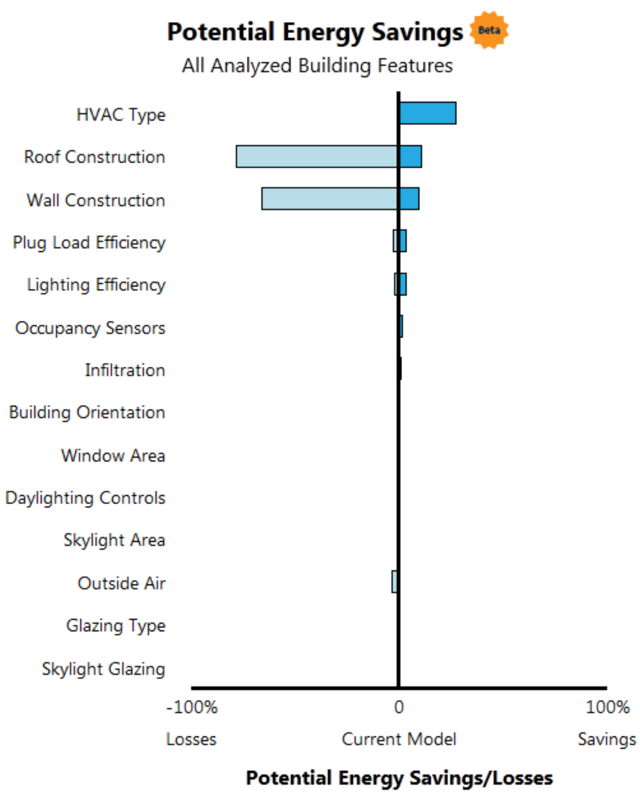




Seymour 4537-Modeled End Use Breakdowns and Potential Energy Savings Charts







Appendix F: Building Feature Design Options within Automatic PES Analysis

(from Autodesk Technical Reference Material for the PES Beta on ADN: *Potential Energy Savings Chart– Technical Details* (Autodesk, 2013)

Definition of Building Feature Design Options

When defining the building type and project location in the Energy Settings dialog, a template is automatically selected from Green Building Studio and applied to the energy analytical model. This template contains the definitions of multiple variations of building feature design options that will be applied when generating simulation data for the Potential Energy Savings Analysis chart.

The specific set of building feature design options applied to the building is driven by two main characteristics of the building model: building type and location. Building size and height are then used to refine the selection of appropriate HVAC and construction systems.

Building Feature Design Options

HVAC Type

From the system types typical for the building type and size, a low performing system, relatively code compliant system, and very high-performing system were analyzed. Find the building type, climate, size and height in the tables below to see the specific systems analyzed for the building.

Selected HVAC Types for Building Type: Commercial Buildings, Large, all ASHRAE climate zones

Building Type	Design Alt	Description
Commercial Buildings - Large	HVC_5	Chiller 5.96 COP, Boilers 84.5 thermal efficiency and room level 4-pipe fan coil units.
	HVC_6	Chiller 5.96 COP with electric baseboards and/or reheat and variable volume central air handlers
	HVC_5	Chiller 5.96 COP, Boilers 84.5 thermal efficiency and room level 4-pipe fan coil units.
	HVC_9	Chiller 5.96 COP, Boilers 84.5 thermal efficiency and room level 2-pipe fan coil units.
	HVC_28	More than 300 ton water-cooled centrifugal chiller 0.47 kW/ton, 86% boiler, premium efficiency with reheat, VAV fan control, VSD pumping,
	HVC_27	150-300 ton water-cooled centrifugal chiller 0.50 kW/ton, 86% boiler, premium efficiency with reheat, | VAV fan control, VSD pumping,.

	HVC_31	Packaged VAV, HW reheat, underfloor air distribution
	HVC_3	11.3 EER medium and large packaged VAV with 84.8% boiler heating
	HVC_4	Chiller 5.96 COP, Boilers 84.5 thermal efficiency and variable volume central air handlers

Note 1: Commercial buildings include Automotive Facility, Convention Center, Courthouse, Dining Bar Lounge Or Leisure, Dining Cafeteria Fast Food, Dining Family, Exercise Center, Fire Station, Gymnasium, Healthcare Clinic, Hospital Or Healthcare, Library, Manufacturing, Motion Picture Theatre, Museum, Office, Penitentiary, Performing Arts Theater, Police Station, Post Office, Religious Building, Retail, School Or University, Sports Arena, Town Hall, Transportation, Warehouse, and Workshop. Conditions for the large building vary by building type.

Selected HVAC Types for Building Type: Commercial Buildings, Small, all ASHRAE climate zones

Building Type	**Design Alt**	**Description**
Commercial Buildings - Small	HVC_22	Premium Efficiency PTAC systems <15 kBtuh
	HVC_10	12 SEER/8.3 efficient packaged terminal heat pump (PTAC). Typically used in hotel/motel rooms.
	HVC_7	14 SEER/8.3 HSPF Small Split Packaged Heat Pump
	HVC_8	Improved Efficiency Split/Packaged Heat Pump System with 12 SEER and 7.7 HSPF and Temp Economizer - Medium Units 5 - 11 ton
	HVC_34	Premium Efficiency Packaged rooftop, <65 kBtu/h, DX cooling SEER 17, 85% AFUE natural gas heating. Premium efficiency on-demand water heater.
	HVC_6	Chiller 5.96 COP with electric baseboards and/or reheat and variable volume central air handlers
	HVC_1	< 5.5 ton packaged or split HVAC units, with gas heat. SEER = 14, AFUE = 0.9
	HVC_2	5 - 11 ton packaged or split HVAC units, with gas heat. SEER = 12, AFUE = 0.9

Selected HVAC Types for Building Types: Multi-Family Housing, Dormitory, Hotel and Motel, all ASHRAE climate zones

Building Type	**Design Alt**	**Description**
Multi-Family Housing, Dorm, Hotel	HVC_10	12 SEER/8.3 efficiency packaged terminal heat pump (PTAC). Typically used in hotel/motel rooms.
	HVC_6	Chiller 5.96 COP with electric baseboards and/or reheat and variable volume central air handlers

	HVC_2	5 - 11 ton packaged or split HVAC units, with gas heat. SEER = 12, AFUE = 0.9
	HVC_31	Packaged VAV, HW reheat, underfloor air distribution
	HVC_3	11.3 EER medium and large packaged VAV with 84.8% boiler heating
	HVC_4	Chiller 5.96 COP, boilers 84.5 thermal efficiency and variable volume central air handlers
	HVC_5	Chiller 5.96 COP, boilers 84.5 thermal efficiency and room level 4-pipe fan coil units.
	HVC_9	Chiller 5.96 COP, boilers 84.5 thermal efficiency and room level 2-pipe fan coil units. Entire system is in either heating or cooling mode by season, not both.

Exterior Wall Construction

From the envelope constructions typical for the climate zone and building size, a low performing option, relatively code compliant option and very high-performing option were analyzed. Find the project's ASHRAE climate zone and building type in the tables below to see the specific constructions analyzed for the building.

Selected exterior wall construction per ASHRAE climate zone, all Building Types except for Single Family Housing

ASHRAE Climate Zone	Exterior Wall Construction (High Rise)		Exterior Wall Construction (Low Rise)	
1 and 2	Wall_1 Wall_4 Wall_174	16" O.C. metal frame wall without insulation 12 inches (R38) of batt or blown-in cavity insulation in 16" O.C. metal frame wall Structurally Insulated Panel (SIP) Wall 12.25 in (311 mm) thick, 48in o.c., R44 insulation	Wall_1 Wall_7 Wall_174	16" O.C. metal frame wall without insulation 9 inches (R30) of batt or blown-in cavity insulation in 16" O.C. 2x10 wood frame wall Structurally Insulated Panel (SIP) Wall 12.25 in (311 mm) thick, 48in o.c., R44 insulation
3, 4, 5, and 6	Wall_1 Wall_172 Wall_174	16" O.C. metal frame wall without insulation 12 inches (R38) of batt or blown-in cavity insulation in 16" O.C. metal frame wall Structurally Insulated Panel (SIP) Wall 12.25 in (311 mm) thick, 48in o.c., R44 insulation	Wall_1 Wall_7 Wall_174	16" O.C. metal frame wall without insulation 9 inches (R30) of batt or blown-in cavity insulation in 16" O.C. 2x10 wood frame wall Structurally Insulated Panel (SIP) Wall 12.25 in (311 mm) thick, 48in o.c., R44 insulation
7 and 8	Wall_1	16" O.C. metal frame wall	Wall_1	16" O.C. metal frame wall

		without insulation		without insulation
	Wall_4	12 inches (R38) of batt or blown-in cavity insulation in 16" O.C. metal frame wall	Wall_7	9 inches (R30) of batt or blown-in cavity insulation in 16" O.C. 2x10 wood frame wall
	Wall_174	Structurally Insulated Panel (SIP) Wall 12.25 in (311 mm) thick, 48in o.c., R44 insulation	Wall_174	Structurally Insulated Panel (SIP) Wall 12.25 in (311 mm) thick, 48in o.c., R44 insulation

Note: If a building has more than 3 stories, it is considered a high rise building. Otherwise it is a low rise building.

Selected exterior wall construction per ASHRAE climate zone for Single Family Housing

ASHRAE Climate Zone	Design Alt	Exterior Wall Construction
1 and 2	Wall_5	16" O.C. wood frame wall without insulation
	Wall_7	9 inches (R30) of batt or blown-in cavity insulation in 16" O.C. 2x10 wood frame wall
	Wall_8	12 inches (R38) of batt or blown-in cavity insulation in 16" O.C. wood frame wall
3, 4, 5, and 6	Wall_5	16" O.C. wood frame wall without insulation
	Wall_7	9 inches (R30) of batt or blown-in cavity insulation in 16" O.C. 2x10 wood frame wall
	Wall_8	12 inches (R38) of batt or blown-in cavity insulation in 16" O.C. wood frame wall
7 and 8	Wall_5	16" O.C. wood frame wall without insulation
	Wall_7	9 inches (R30) of batt or blown-in cavity insulation in 16" O.C. 2x10 wood frame wall
	Wall_8	12 inches (R38) of batt or blown-in cavity insulation in 16" O.C. wood frame wall

Glazing Type

From the glazing types typical for the specific climate zone and building size, a low performing option, relatively code compliant option, and very high-performing option were analyzed. Find the project's ASHRAE climate zone and building type in the tables below to see the specific glazing types analyzed for the building.

Selected glazing type per ASHRAE climate zone, all Building Types

ASHRAE Climate Zone	Design Alt	Window Glazing Type
1 and 2	GLz_1 GLz_4 GLz_28	Pyrolitic, high solar heat gain, high visible transmittance (U = 0.76, SHGC = 0.77, Tvis = 0.82) High solar heat gain, high visible transmittance (U = 0.35, SHGC = 0.67, Tvis = 0.72) Insulated Translucent Wall Panel, Ice Blue exterior & White interior (U=0.10, SHGC = 0.06, Tvis = 0.04)
3, 4, 5, and 6	GLz_1 GLz_4 GLz_7	Pyrolitic, high solar heat gain, high visible transmittance (U = 0.76, SHGC = 0.77, Tvis = 0.82) High solar heat gain, high visible transmittance (U = 0.35, SHGC = 0.67, Tvis = 0.72) Low solar heat gain, medium visible transmittance (U = 0.23, SHGC = 0.28, Tvis = 0.41)
7 and 8	GLz_1 GLz_4 GLz_13	Pyrolitic, high solar heat gain, high visible transmittance (U = 0.76, SHGC = 0.77, Tvis = 0.82) High solar heat gain, high visible transmittance (U = 0.35, SHGC = 0.67, Tvis = 0.72) Very low heat conductance, used in very cold climates (U = 0.22, SHGC = 0.47, Tvis = 0.64)

Skylight Glazing

ASHRAE Climate Zone	Design Alt	Skylight Glazing Type
1 and 2	SkyGlz_18 SkyGlz_19 SkyGlz_29	Mid-Range Performance Skylight (U = 0.69, SHGC = 0.49) High Performance Skylight (U = 0.35, SHGC = 0.27) Insulated Translucent Roof Panel, Ice Blue exterior & White interior, (U = 0.10, SHGC = 0.07, Tvis = 0.04)

3, 4, 5, and 6	SkyGlz_18 SkyGlz_19 SkyGlz_27	Mid-Range Performance Skylight (U = 0.69, SHGC = 0.49) High Performance Skylight (U = 0.35, SHGC = 0.27) Insulated Translucent Roof Panel, Aqua exterior & White interior, (U = 0.29, SHGC = 0.23, Tvis = 0.20)
7 and 8	SkyGlz_18 SkyGlz_19 SkyGlz_29	Mid-Range Performance Skylight (U = 0.69, SHGC = 0.49) High Performance Skylight (U = 0.35, SHGC = 0.27) Insulated Translucent Roof Panel, Ice Blue exterior & White interior, (U = 0.10, SHGC = 0.07, Tvis = 0.04)

Roof Construction

From the roof constructions typical for the climate zone and building size, a low performing option, relatively code compliant option and very high-performing option were analyzed. Find the project's ASHRAE climate zone and building type in the tables below to see the specific constructions analyzed for the building.

Selected roof construction per ASHRAE climate zone, all Building Types

ASHRAE Climate Zone	Design Alt	Roof Construction
1 and 2	Roof_14 Roof_15 Roof_170	4 inches (R15) of batt or blown-in insulation between metal 2x framing members 12 inches (R38) of batt or blown-in attic/roof insulation between and over metal 2x framing members Cool Roof; R38 continuous insulation over roof deck
3, 4, 5, and 6	Roof_13 Roof_15 Roof_24	Metal frame roof without insulation 12 inches (R38) of batt or blown-in attic/roof insulation between and over metal 2x framing members 18-20 inches (R60) continuous rigid insulation over roof deck
7 and 8	Roof_14 Roof_175 Roof_15	4 inches (R15) of batt or blown-in insulation between metal 2x framing members Structurally Insulated Panel (SIP) Roof 10.25 in (260 mm) thick, 48in o.c., R36 insulation 12 inches (R38) of batt or blown-in attic/roof insulation between and over metal 2x framing members

Lighting Efficiency and Plug Load Efficiency

Typically, the lighting power density and equipment power density varies in the baseline model by building use and space type. Multiple variations in the LPD and EPD for the model were analyzed by applying percentage variations to the baseline model submitted. The same variations were applied to all building types, sizes and climate zones.

Selected lighting power density (LPD), all Building Types and all ASHRAE climate zones

Design Alt	Description
LtEff_3	20% less of the Lighting Power Density (LPD) of the base model
LtEff_4	30% less of the Lighting Power Density (LPD) of the base model
LtEff_14	20% more of the Lighting Power Density (LPD) of the base model

Refer to the GBS default table for the default LPD

Selected equipment power density (EPD), all Building Types and all ASHRAE climate zones

Design Alt	Description
Epq_3	20% less of the Equipment Power Density (EPD) of the base model
Eqp_4	30% less of the Equipment Power Density (EPD) of the base model
Eqp_14	20% more of the Equipment Power Density (EPD) of the base model

Refer to the GBS default (Table A1) for the default EPD

Daylighting Controls and Occupancy Sensors

Includes on/off options for daylighting dimming controls and occupancy lighting controls. Daylighting control: On/Off controls for lighting systems according to daylight availability. When set to On, lighting is controlled by up to 2 daylight sensors per zone placed automatically by Green Building Studio

Daylighting control options, all Building Types and all ASHRAE climate zones

Design Alt	Description
DL_1	No daylighting control
DL_2	With daylighting control

Occupancy lighting control: On/Off controls for lighting systems according to occupancy. When set to 'On', lighting is turned off automatically when no occupants are in the space.

Available occupancy lighting control options, all Building Types and all ASHRAE climate zones

Design Alt	Description
OS_1	No lighting control with occupancy sensors
OS_2	With lighting control with occupancy sensors

Outside Air and Infiltration

Includes options for outside air intake per area and per person, and infiltration rate.
Outside air intake per person: the flow rate of fresh air intentionally introduced into building.
Infiltration rate: the unconditioned outdoor air leak into conditioned spaces.

Outside air intake per person options, all Building Types and all ASHRAE climate zones

Design Alt	Description
OAp_13	10% more of the default outside air per person
OAp_14	20% more of the default outside air per person

Refer to the GBS default (Table A1) for the default outside air per person

Infiltration rate options, all Building Types and all ASHRAE climate zones

Design Alt	Description
Inf_2	25% less of the default infiltration rate
Inf_3	50% less of the default infiltration rate

Refer to the GBS default table for the default infiltration rate

Glazing Area and Skylight Area

Window area change options, all Building Types and all ASHRAE climate zones

Design Alt	Description
GLa_7	50% less of the window area of the base model
GLa_6	50% more of the window area of the base model

Skylight area change options, all Building Types and all ASHRAE climate zones

Design Alt	Description
Skla_7	50% less of the skylight area of the base model
Skla_6	50% more of the skylight area of the base model

Building Orientation

Building orientation options, all Building Types and all ASHRAE climate zones

Design Alt	Description
Ornt_3	30 degree clockwise rotation (+30°) of the base model
Ornt_5	60 degree clockwise rotation (+60°) of the base model
Ornt_7	90 degree clockwise rotation (+90°) of the base model
Ornt_9	120 degree clockwise rotation (+120°) of the base model
Ornt_11	150 degree clockwise rotation (+150°) of the base model
Ornt_13	180 degree clockwise rotation (+180°) of the base model
Ornt_23	30 degree counterclockwise rotation (-30°) of the base model
Ornt_21	60 degree counterclockwise rotation (-60°) of the base model
Ornt_19	90 degree counterclockwise rotation (-90°) of the base model
Ornt_17	120 degree counterclockwise rotation (-120°) of the base model
Ornt_15	150 degree counterclockwise rotation (-150°) of the base model

GBS defaults for EPD, LPD, outside air flow per person and infiltration rate

GBS Building Type	EPD (W/ ft²)	LPD (W/ ft²)	Outside Air Flow/Person (cfm/person)	Outside Air Flow/Area (cfm/ ft²)	Infiltration Flow (ACH)
Automotive Facility	1.00	0.90	N/A	1.5	0.25
Convention Center	0.96	1.20	6.57	0.2	0.10
Courthouse	1.00	1.20	6.14	0.2	0.10
Dining Bar Lounge Or Leisure	0.79	1.30	9.96	0.2	0.25
Dining Cafeteria Fast Food	0.79	1.40	9.96	0.2	0.25
Dining Family	0.79	1.60	10.81	0.2	0.10
Dormitory	1.00	1.01	8.48	0.2	0.25
Exercise Center	1.00	1.01	22.88	0.2	0.25
Fire Station	1.00	1.01	18.01	0.2	0.10
Gymnasium	1.00	1.00	27.55	0.2	0.10
Healthcare Clinic	1.18	1.01	16.95	0.2	0.10
Hospital Or Healthcare	1.18	1.20	27.55	0.2	0.10
Hotel	0.50	1.01	11.65	0.2	0.10
Library	1.00	1.30	18.01	0.2	0.10
Manufacturing	1.00	1.30	16.95	0.2	0.10
Motel	0.50	1.01	11.65	0.2	0.25
Motion Picture Theatre	0.54	1.20	5.72	0.2	0.10
Multi Family	1.00	0.70	N/A	0.06	0.25
Museum	1.00	1.10	9.75	0.2	0.10
Office	1.34	1.01	18.01	0.2	0.10
Parking Garage	0.30	0.30	N/A	1.5	5.00
Penitentiary	1.00	1.01	10.38	0.2	0.25
Performing Arts Theater	0.54	1.60	11.44	0.2	0.25
Police Station	1.00	1.01	10.38	0.2	0.10
Post Office	1.00	1.10	18.01	0.2	0.10
Religious Building	0.96	1.30	5.93	0.2	0.10
Retail	0.94	1.50	16.53	0.2	0.10
School Or University	1.00	1.20	14.20	0.2	0.25
Single Family	0.43	0.45	N/A	0.06	0.50
Sports Arena	1.00	1.10	8.48	0.2	0.10
Town Hall	1.00	1.10	6.57	0.2	0.10
Transportation	1.00	1.01	8.69	0.2	0.10
Warehouse	0.43	0.80	N/A	0.06	0.10
Workshop	1.00	1.40	20.13	0.2	0.10

Note: When outside airflow per person is N/A, outside airflow per area is set to default.